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Technical Report

DEEP-OCEAN BIODETERIORATION OF MATERIALS — PART VI. ONE YEAR AT 2,370 FEET

May 1967

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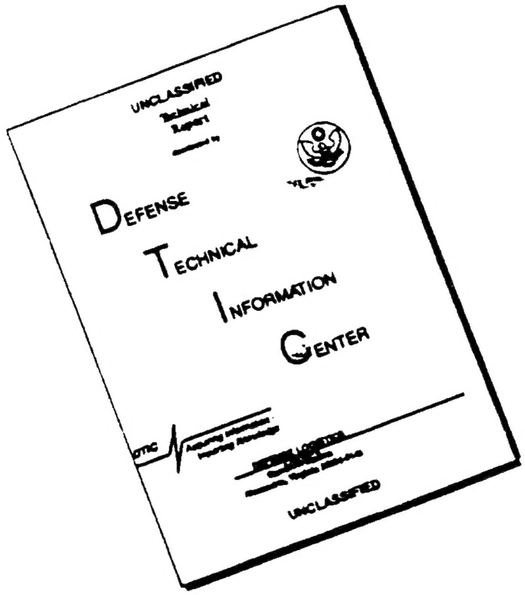

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DEEP-OCEAN BIODETERIORATION OF MATERIALS — PART VI. ONE YEAR AT 2,370 FEET

Technical Report R-525

Z-F015-01-99-006

by

James S. Muraoka

ABSTRACT

As Part VI of a series of reports on the biological deterioration of materials in the deep ocean, this report covers the data obtained after exposing metallic and nonmetallic specimens for 13.4 months on the floor of the Pacific Ocean at a depth of 2,370 feet (Test Site II). The specimens were attached to a Submersible Test Unit that was emplaced in April 1965 and retrieved in May 1966. Preliminary examination of the specimens was made aboard ship, and the final examination, tests, and analyses were performed at the Naval Civil Engineering Laboratory.

On recovery, most of the plastic materials and all of the rope specimens were covered with bacterial slime. Cotton and manila ropes were severely deteriorated by marine microorganisms. Wood panels, certain plastics, and manila ropes were attacked by molluscan borers. Some of the plastics were attacked by borers directly from seawater environment without the aid of wood bait pieces. Hydroids and tube-worms were found on metal panels. Sea anemone, snails, and crabs were also found attached to various test panels. The surface of a silicone rubber electrical cable insulation was deteriorated by some marine organisms. Typical fouling organisms such as barnacles and bryozoa were not found. Glass, elastomers, and certain plastics were not adversely affected. Data from evaluation of these specimens are presented.

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The Laboratory invites comment on this report, particularly on the results obtained by those who have applied the information.

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PREFACE

The U. S. Naval Civil Engineering Laboratory is conducting a research program to determine the effects of the deep ocean environment on materials. This research will be of great value in establishing the best materials to be used in deep ocean construction in the Navy's conquest of "inner space."

A Submersible Test Unit (STU) was designed on which many test specimens can be mounted. The STU can be lowered to the ocean bottom and left for long periods of exposure. This report deals with STU II-2, in place for 13.4 months at a depth of 2,370 feet. The test site is about 75 nautical miles west of Port Hueneme, California.

INTRODUCTION

As part of a research program to determine the effects of the deep ocean environment on various materials, the U. S. Naval Civil Engineering Laboratory (NCEL) in March 1962 placed the first of a series of Submersible Test Units, designated STU I-1, on the ocean floor in 5,300 feet of water at Test Site I off the coast of California (Figure 1). Since then 5 additional STUs have been placed on the sea floor and recovered; these are listed in Table 1 with pertinent information about each STU.

STU II-2 was recovered in May 1966 after 13.4 months on the sea floor in 2,370 feet of water. A sketch of the STU II-2 system as installed is shown in Figure 2. The STU was loaded with 2,588 specimens of 811 materials. The majority of these materials were metal and metal alloys for the study of corrosion. For studying biodeterioration, nonmetallic materials, such as woods, ropes, glass, rubber, and plastics, were assembled in two bio-racks which were attached to the side of the STU.

This report describes the materials and presents the methods used for attracting, collecting, and evaluating deep sea fouling and boring organisms and the results of field and laboratory investigations of the materials recovered from STU II-2.

Before the materials were exposed in the deep ocean on the STUs, a literature search was made on the effects of deep ocean animals on materials, and the findings of that study were reported in Reference 6.

RESEARCH METHODS

Oceanographic Information

Concurrently with the STU program, numerous cruises have been made to the STU sites to collect oceanographic and biological data. Information has been gathered about the environmental parameters, such as salinity, temperature, dissolved oxygen concentration, and biological activity. Such information is essential in evaluating changes in the materials exposed on the ocean floor, especially the corrosion of metals. The environment for Test Site II (2,370-foot depth) is presented in Table 2.

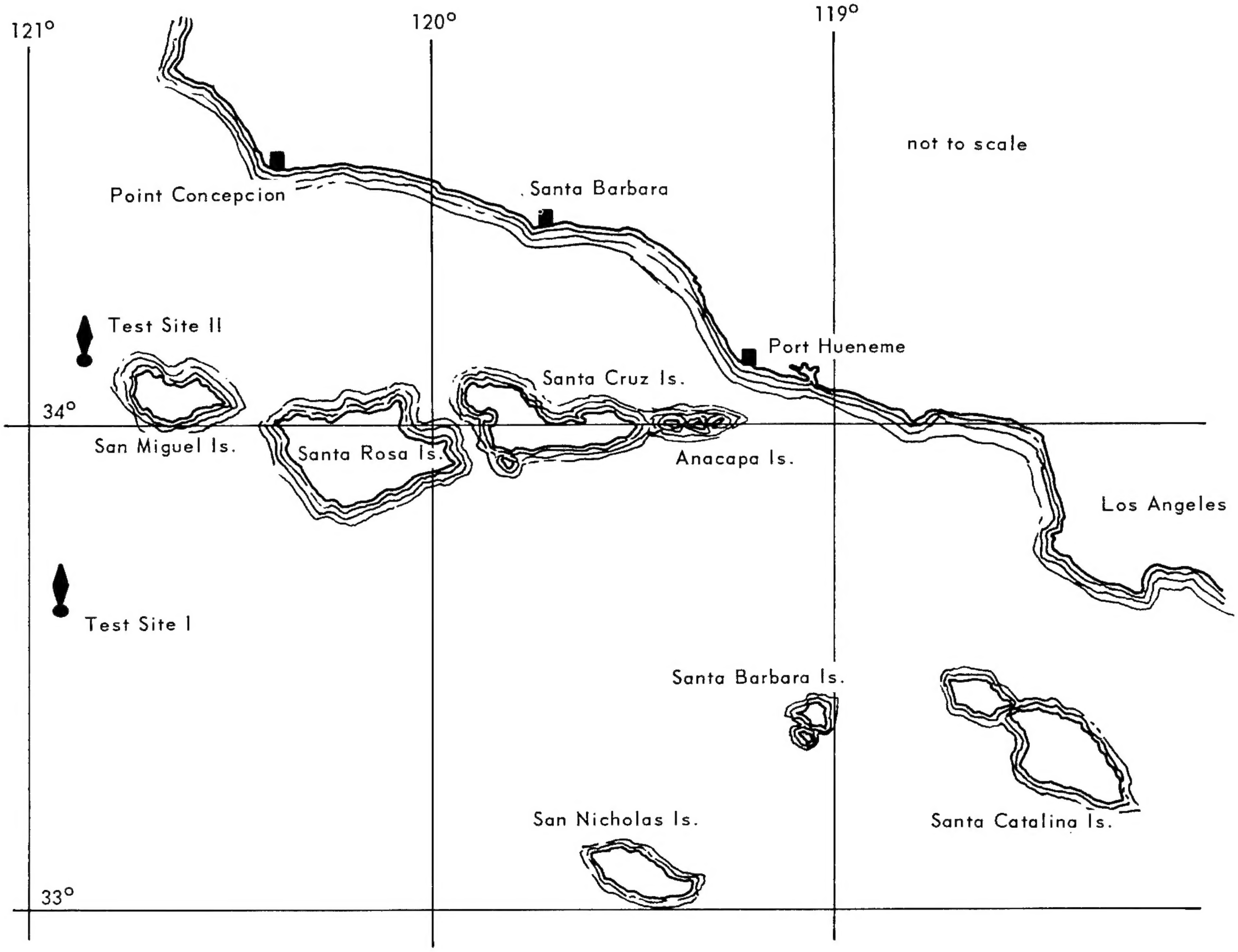


Figure 1. Test Site I (nominal depth of 6,000 feet) and Test Site II (nominal depth of 2,500 feet).

Table 1. Pertinent Data Associated With Each Emplaced STU

STU No.	Test Site	Depth (ft)	Location	Date Emplaced	Date Recovered	Exposed Period (mo)	No. of Materials	No. of Specimens	Result Published (Ref. No.)
I-1	I	5,300	$33^{\circ}46'$N $120^{\circ}37'$W	March 1962	February 1965	35.5	396	1,282	1 (Part III)
I-2	I	5,640	$33^{\circ}44'$N $120^{\circ}45'$W	October 1963	October 1965	25	429	1,521	2(Part V)
I-3	I	5,640	$33^{\circ}44'$N $120^{\circ}45'$W	October 1963	February 1964	4.1	398	1,367	3 (Part I)
I-4	I	6,780	$33^{\circ}46'$N $120^{\circ}46'$W	June 1964	July 1965	13.4	567	1,852	4 (Part IV)
II-1	II	2,370	$34^{\circ}06'$N $120^{\circ}42'$W	June 1964	December 1964	6.5	603	2,385	5 (Part II)
II-2	II	2,370	$34^{\circ}06'$N $120^{\circ}42'$W	April 1965	May 1966	13.4	811	2,588	This report (Part VI)

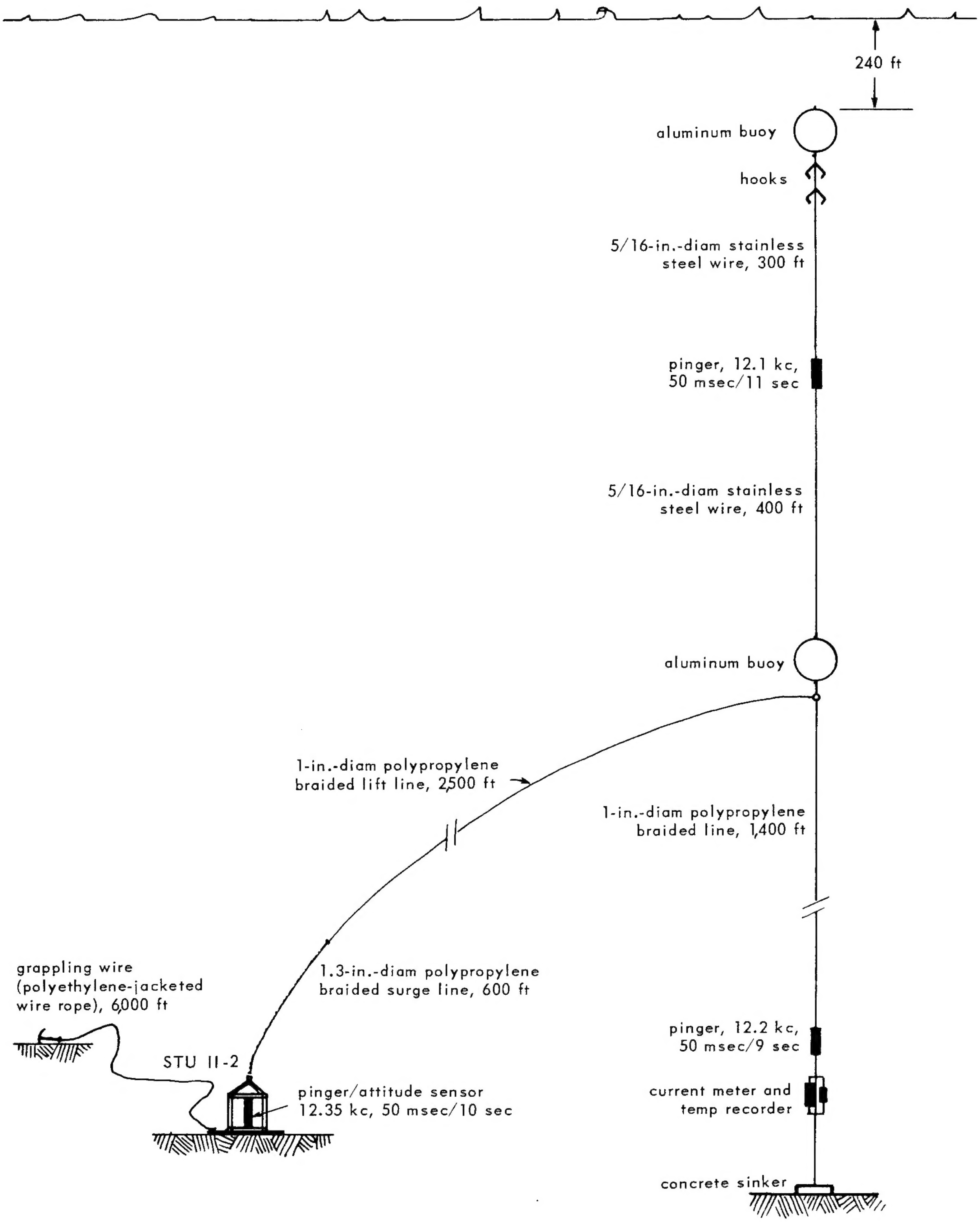


Figure 2. STU II-2 Complex as designed.

Table 2. Environment at Test Site I and II (Average Values)

Environmental Factors	Surface Water	Test Site I	Test Site II
Depth, ft	—	5,640	2,370
Water temperature, °C	14.0	2.5	5.0
Dissolved oxygen content, ml/l	5.8	1.26	0.30
Salinity, o/oo (ppt)	33.6	34.56	33.4
pH	7.9-8.0	7.44	7.6
Hydrostatic pressure, psi	—	2,482	1,043
Current, knots	—	0.033	0.06 (0.3 max)
Sediment	—	Green mud containing glauconite, Foraminifera tests, quartz, etc.	Green mud containing glauconite, Foraminifera tests, quartz, etc.

Test Site II was selected because the area provides a nominal 2,500-foot depth reasonably representative of the open-sea conditions in the eastern part of the Pacific Ocean. It is located about 75 nautical miles west of Port Hueneme, California.

In addition, a depth of about 2,500 feet was selected because the dissolved oxygen content in seawater falls to a relatively low value. This depth is known as "the minimum oxygen zone." Below and above this depth, the dissolved oxygen content increases. The underlying causes of "the minimum oxygen zone" are still imperfectly understood.

Because the rates of corrosion of certain metals and alloys are greatly influenced by the concentration of dissolved oxygen in seawater, it was desired to investigate the effects of the minimum oxygen zone on materials.

Biological Activity

Rock Samples. Rock specimens were desired from this area in order to enable study of any fouling organisms attached to the rocks. Such animals could be expected to attach themselves to test specimens placed there. Before placing the STU at this test site, a dredge, made of 10-inch-diameter by 36-inch-long steel pipe with retaining rods welded across the lower end of the pipe, was lowered to the ocean floor from the oceanographic vessel, USNS Davis (AGOR-5), and the area was dredged for rock specimens. Several passes were made across the area, but no specimen was found.

Sediment Samples. Marine bacteria are among the major biological agents in the deterioration and fouling of various materials submerged in the sea. To determine the type and activity of bacteria found in the deep sea, sediment samples were obtained from the ocean bottom and analyzed in the laboratory by means of standard microbiological methods. The types of bottom samplers used, the media used to grow the microorganisms, and the result of bacteriological analysis of the sediment samples are presented in Reference 3.

Some of the sediment samples which were obtained from this site were washed through a screen to collect mud-dwelling organisms; those found were bottled and preserved in a 5% glycerol-alcohol solution for laboratory analysis. Amphipods, polychaete worms, and brittle stars were the most abundant marine organisms collected in the vicinity of Test Site II.

Test Materials. For evaluating deep sea biological effects on nonmetallic specimens, two bio-racks (Figure 3) were attached to the STU. Each rack held several 3-foot-long plastic rods and tubes and a 12 x 30 x 1/8-inch laminated phenolic plastic sheet. Numerous smaller test specimens, including wood specimens, were attached to the plastic sheets; one sheet was secured to the upper section of one bio-rack, and an identical sheet was secured to the bottom section of the other. In order to expose the test materials to biodeterioration in mud as well as in water, the two racks were

attached to the STU so that the lower portions would be either near the bottom sediment or buried in it and the upper portions would be exposed to seawater 3 to 4 feet above the mud line (Figure 4).

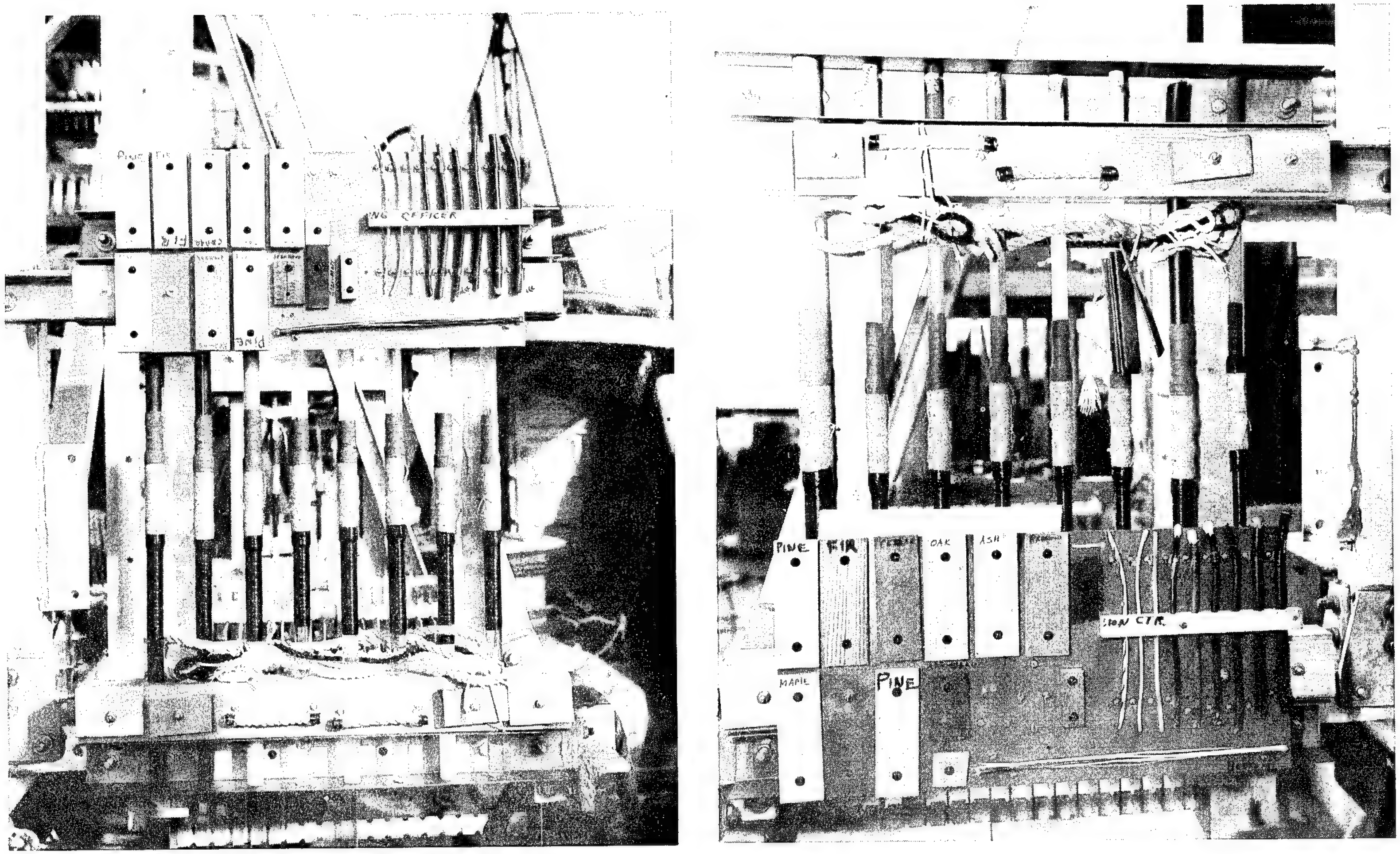
The 2x6x1/2-inch wood panels were cut from sound lumber, and the surfaces were cleaned with alcohol and then covered with plastic to avoid contamination. The plastic covers were removed just before the test specimens were submerged. The wood panels were employed to collect specimens of any deep sea fungi and marine borers which may have been present on the ocean floor.

The sections of the 3-foot-long plastic rods, tubes, and pipe, and the rubber tubes were treated in different ways. One section of each specimen was roughened; a second section was wrapped in burlap; a third section was taped with plastic; a fourth section was taped with rubber electrical tape; and a fifth section was left smooth. The various wrappings were to provide a favorable foothold for the attachment and growth of deep sea fouling and boring organisms. A large piece of untreated fir was fitted around both unwrapped ends of each specimen to attract and lead the borers into direct contact with each plastic specimen.

Four different kinds of rope, made of synthetic plastic fiber (nylon and polypropylene) and of natural fiber (cotton and manila), were placed on the bio-racks. Electrical cables covered with rubber or plastic insulation of various thicknesses were also placed on the racks. A small piece of pine was fitted around each cable specimen to act as bait for marine borers. Another group of electrical conductors placed on the bio-racks consisted of No. 16 tin-coated copper wire with 0.015-inch-thick insulation. The materials used in the formulation of the insulation are presented in Table 3. The wire specimens were 15 inches long, and both ends of each specimen were sealed with two coats of silicone rubber cement. The rope and conductor specimens were positioned so that one set of each would be buried in the sediment (in which bacteria are ordinarily most active) and identical sets would be exposed about 3 feet above the sediment.

In addition to the materials placed in the bio-racks, test specimens were also placed inside a sterile plastic test chamber which was secured to the side of the STU about 4 feet above the mud line (Figure 5). The test chamber consisted of 5-inch-diameter (OD) by 24-inch-long acrylic tube, both ends of which were covered with 0.45-micron membrane filters to keep out marine bacteria. Before submergence, the materials placed inside the tube were sterilized with ethylene oxide gas. Identical materials were also placed outside the test chamber and exposed to the natural sea environment. This test was initiated to determine the role played by marine microorganisms in the deterioration of cotton and manila ropes and corrosion of metallic specimens. Materials placed in the bio-racks and in the plastic test chamber are listed in the Appendix.

Metal test specimens were also placed on the STU, but materials containing antifouling paints or other toxic substances were excluded. The velocity of the current at a depth of 2,370 feet (about 0.06 knot) was not great enough to carry away any water-soluble toxic substance which might change the behavior of the natural biological fauna found in the immediate vicinity of the STU.



(a) Wood panels at top of rack.

(b) Wood panels near sediment.

Figure 3. Various kinds of materials assembled in bio-racks before exposure.

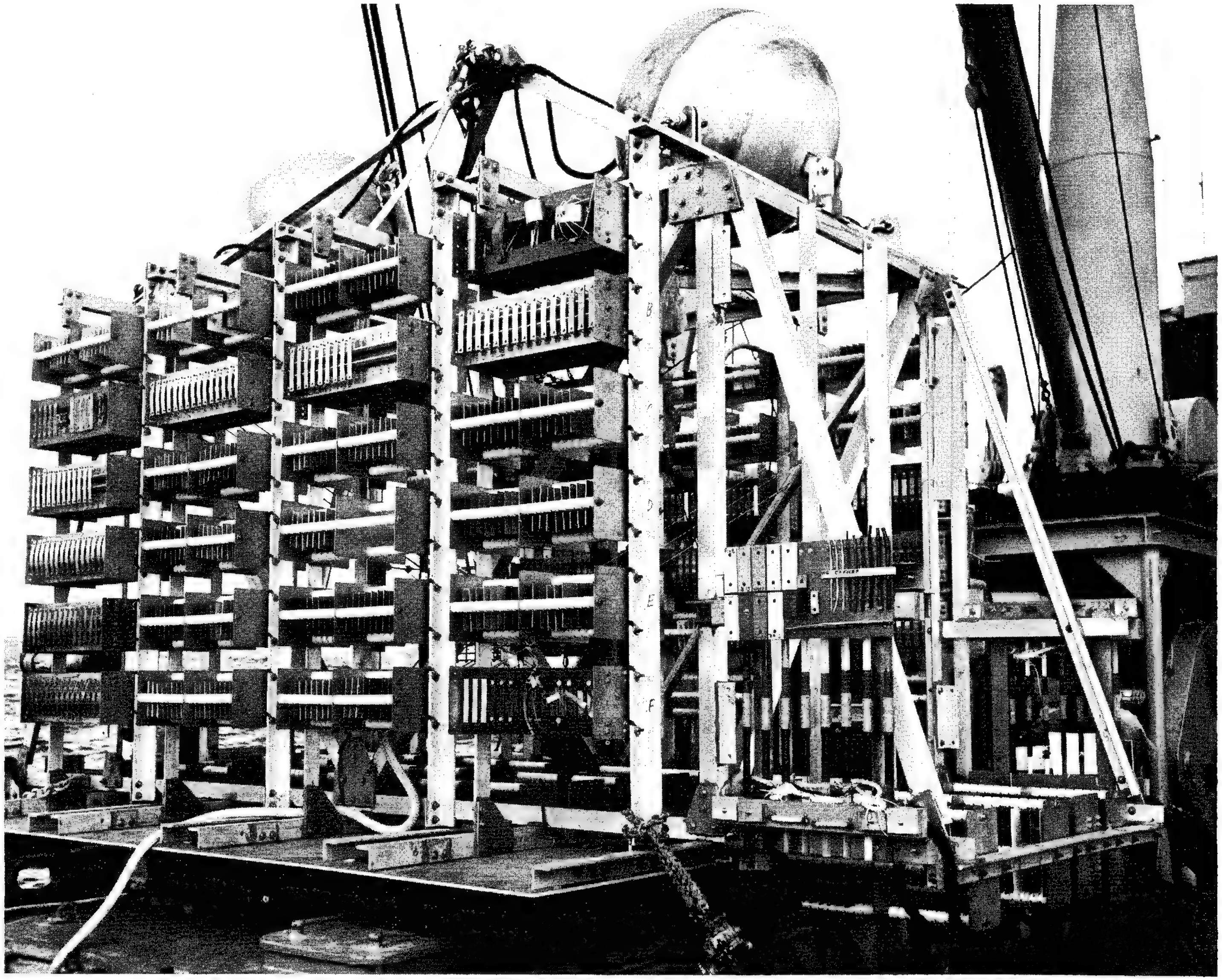


Figure 4. Bio-racks attached to STU II-2 before exposure.

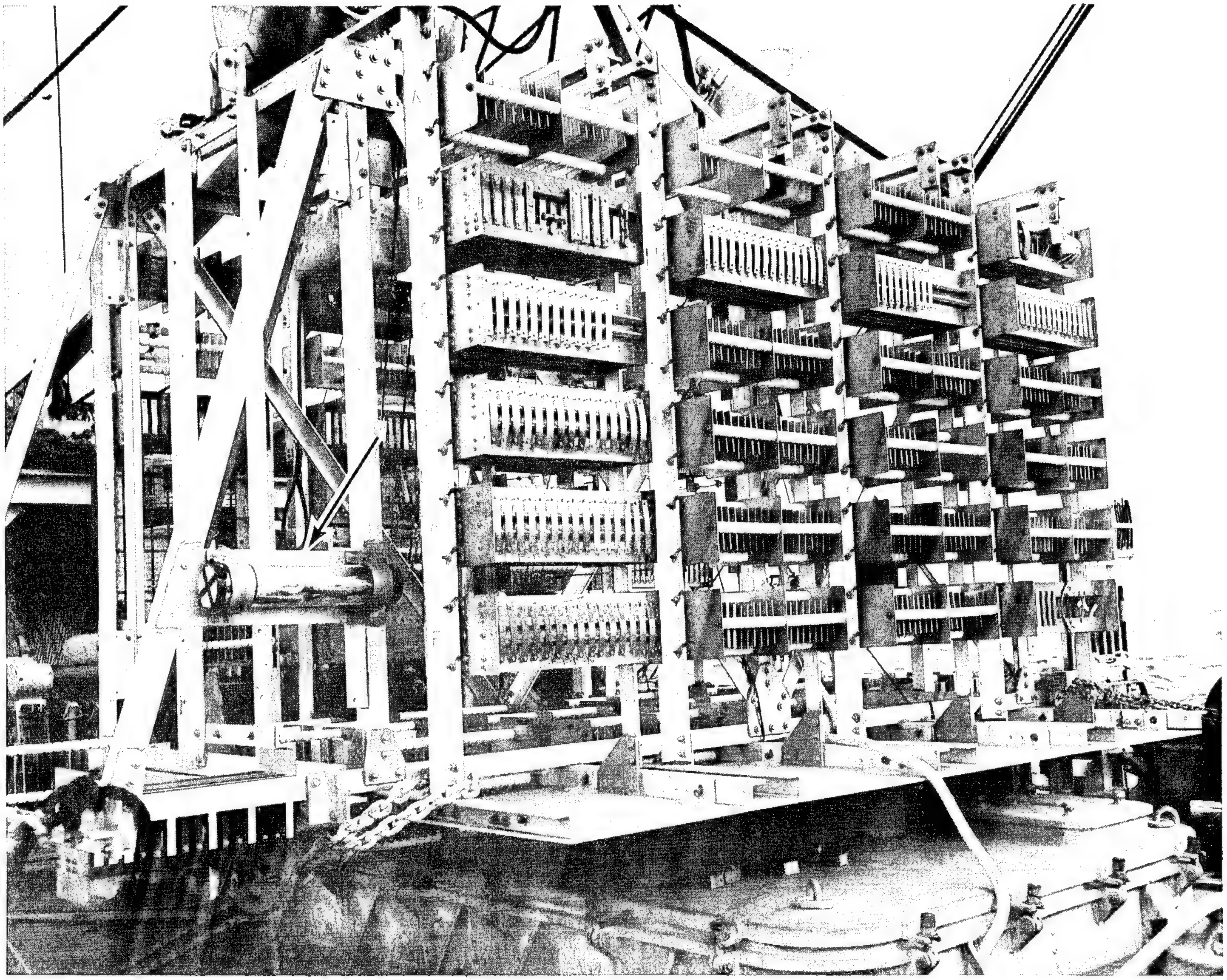


Figure 5. Sterile test specimens placed inside a plastic test chamber and attached to STU II-2.

Table 3. Materials Used in the Formulation of Insulating Materials Tested

Test Specimen	Plasticizer	Filler	Antioxidant
Polyethylene (standard polyethylene insulation)	—	—	—
Polyvinyl chloride	—	—	—
Government rubber styrene (styrene butadiene rubber) GR-S (SBR)	Cumarone-indene resin and micro-crystalline wax	Hard clay and water-ground whiting	Polymerized trimethyl dihydroquinoline
Silicone rubber	—	—	—
Neoprene (type W)	Light process oil and petroleum	Hard clay	4, 4 thiobis (6-tert-butyl m-creosol)

RESULTS

Marine Growth on STU Rigging Complex

Generally there was very little fouling growth on various recovered materials. Hydroids and slime growths were found on the surface of recovered components such as buoys, shackles, polypropylene rope, and pinger casings. Some of the hydroids found attached to the lift line were about 1 inch long.

Typical fouling organisms such as barnacles, sea squirts, and bryozoa usually found on submerged objects in harbors and shallow water were not found attached to any of the recovered materials.

Treatment of Recovered Test Materials

As soon as the recovered STU was placed on the deck of the ship, the test panels were examined, and any attached organisms were photographed. The animals were then carefully lifted from the test specimens and preserved in a 5% glycerol-alcohol solution for further examination and analysis in the laboratory.

As soon as the STU was secured to the deck, the bio-racks attached to the side of the STU were disassembled (Figure 6). The individual test specimens were placed in plastic bags for later examinations, tests, and evaluation in the laboratory.

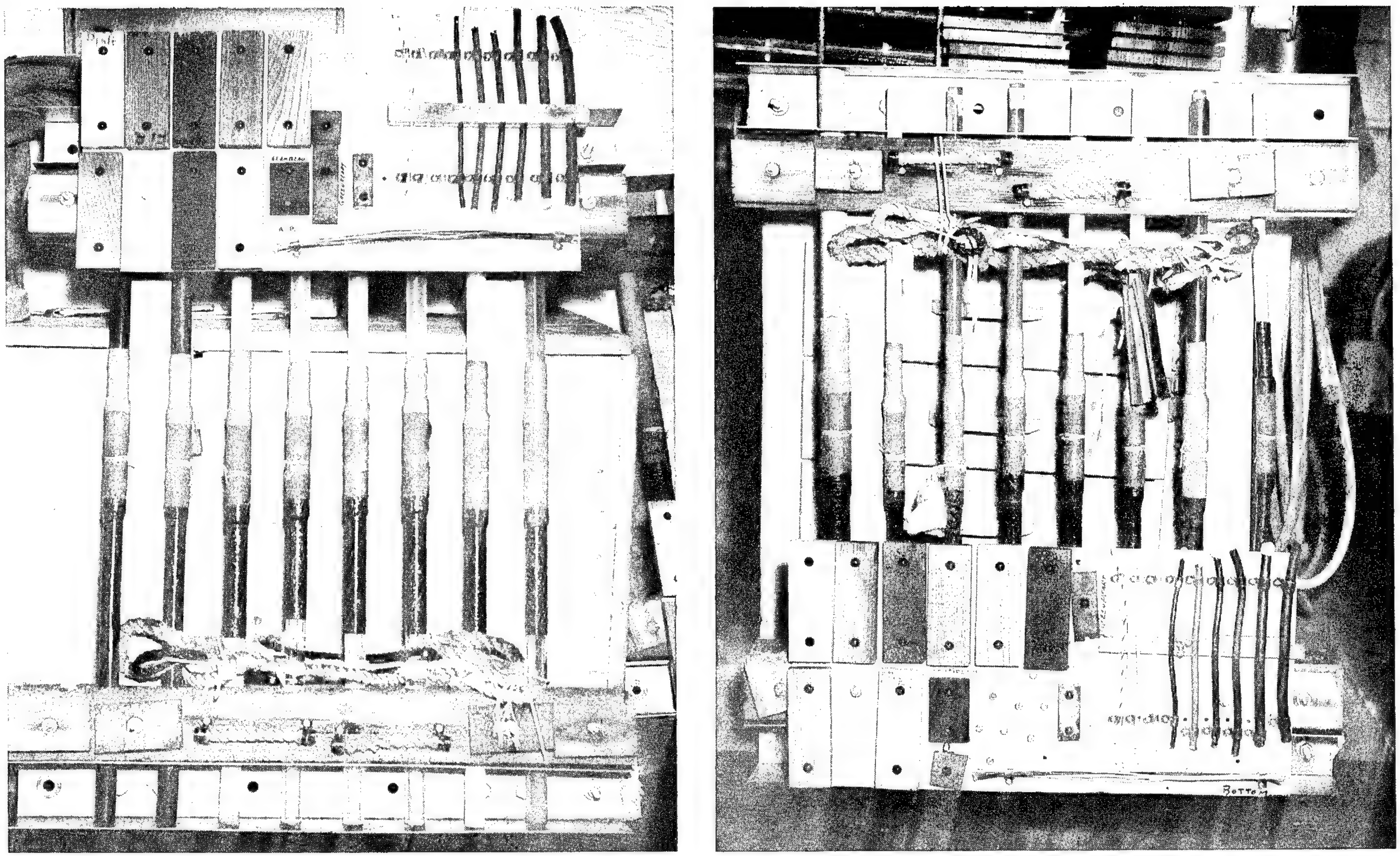


Figure 6. Bio-racks immediately after recovery from the sea. Compare with Figure 3.

The wood panels, riddled with marine borers, were soaked in an alcohol solution to prevent decay and were placed in plastic bags. The wood panels used for fungi determination were placed directly into sterile plastic bags, sealed, and stored in the ship's refrigerator. Rope specimens for the isolation of marine microorganisms were also placed in sterile plastic bags and stored in a refrigerator. A 3-inch section was cut from each end of the plastic rods and tubes and then placed inside individual plastic containers filled with fresh seawater. This was to retain the moisture in the plastics recovered from the sea for conducting moisture and hardness tests in the laboratory.

Marine Growth on Test Materials

Metal Panels. Generally there was very little fouling growth on metal panels. Most of the fouling growth found on the panels were species of hydroids (Figure 7). Some species with treelike branching growths were caught on the surface of the panel (Figure 8). Hydroids were found on panels such as stainless steel and titanium, which were not covered with corrosion products. Very little or no growth was found on panels such as mild steel and copper-based alloys, which were covered with corrosion products.

Several tubeworms (3-inch-long tubes made of mud and bottom debris) were found on stainless steel panels which were partially buried in the sediment (Figures 9 and 10). Another variety of tubeworms (tubes made of white calcareous materials) were found on stainless steel and titanium panels (Figure 11). A small pecten about 1/8 inch in diameter was also found attached to a titanium panel which was partially buried in the sediment (Figure 12). Several deep sea crabs (Figure 13), gastropods (Figure 14), and a large sea anemone (Figure 15) were found on various test panels.

Typical fouling organisms such as barnacles, bryozoa, mussels, and tunicates found on submerged materials in shallow waters were not found on panels submerged on the ocean floor in 2,370 feet of water.

The corrosive effects of the deep ocean environment on various metallic specimens from previous STUs are presented in Reference 7.

Wood Panels. Various kinds of untreated wood panels (1/2 x 2 x 6-inch) such as pine, fir, ash, maple, cedar, oak, and redwood were exposed to determine the effects of marine organisms on different woods. All the wood panels were attacked by marine borers and sustained light to heavy damage. Redwood and cedar were the most severely damaged; maple, pine, oak, and ash were moderately damaged; and fir sustained the lightest damage (Figures 16 & 17).

The diameter of the shells of the majority of the borers in these woods measured about 1/8 inch. Some borers in cedar and redwood had penetrated about 3/4 inch into the wood from the cut end of a panel (Figures 18 & 19). The loss in weight of each of these panels due to borer damage is presented in the Appendix.

Figure 7. Closeup view of hydroids attached to the surface of a titanium panel.

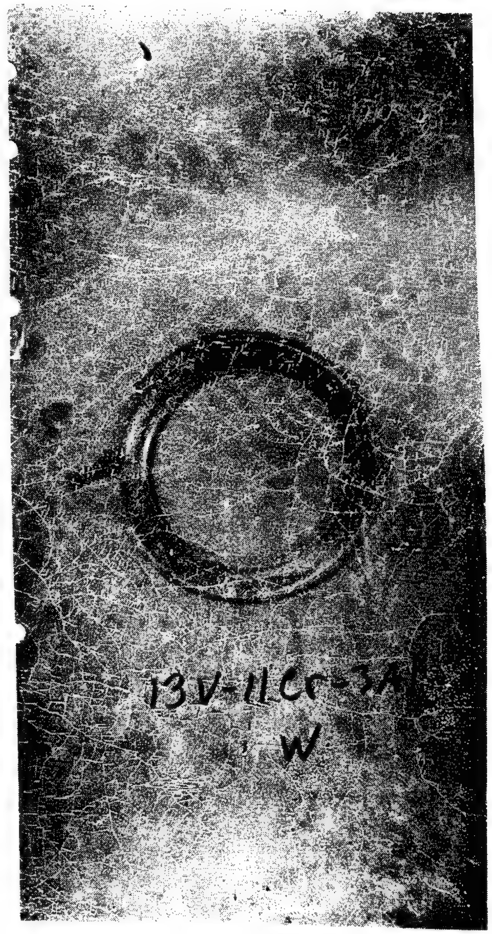


Figure 8. Hydroid growth on titanium test panel.

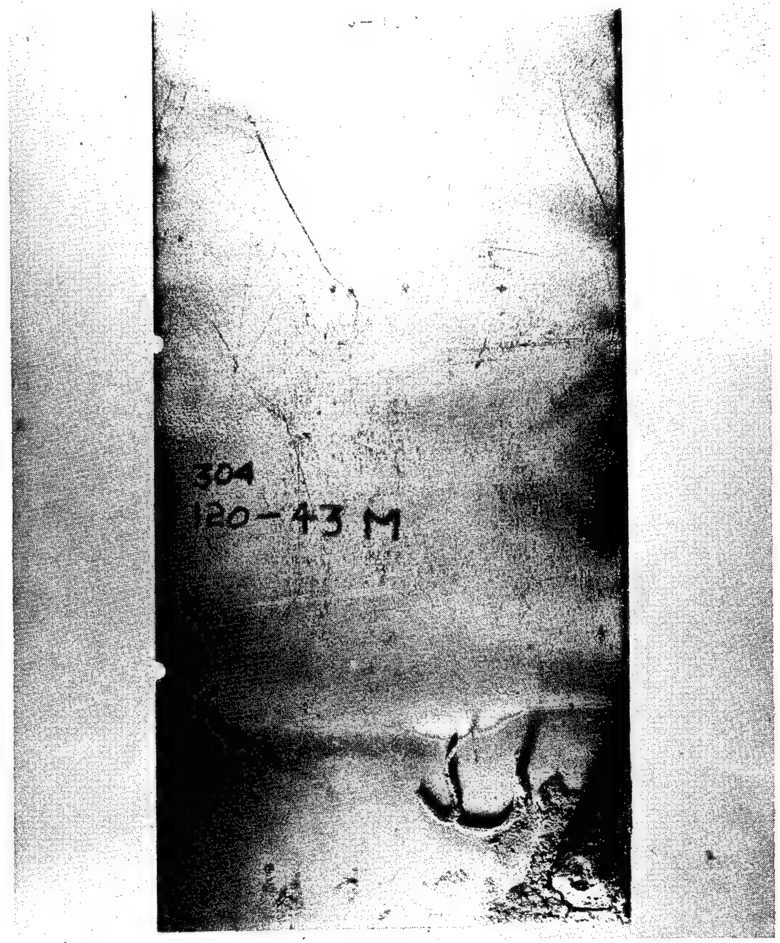


Figure 9. Tubeworm on a bottom section of a stainless steel panel exposed in the sediment.

Figure 10. Closeup view of a tubeworm shown in Figure 9.

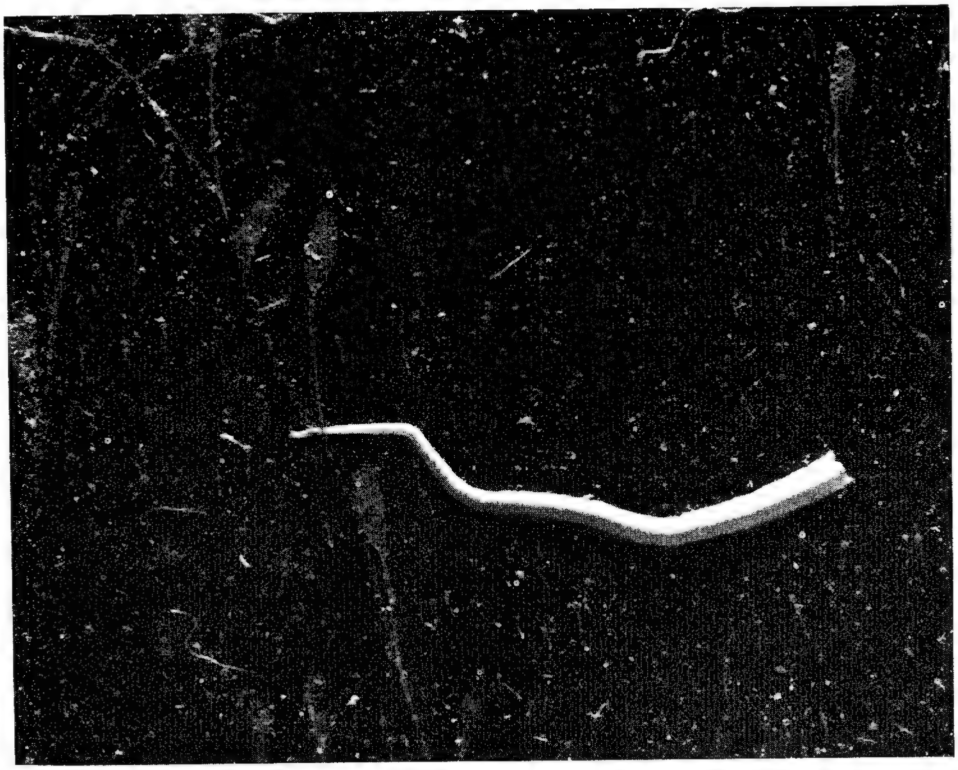


Figure 11. Closeup view of a tubeworm on a titanium test panel.

Figure 12. A 1/8-inch-diameter pecten growing on the surface of a titanium panel.

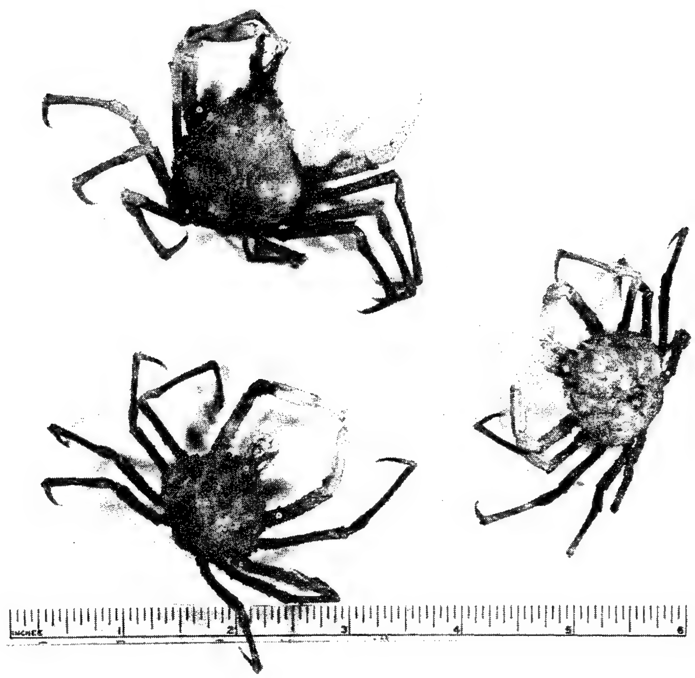


Figure 13. Deep sea spider crabs.

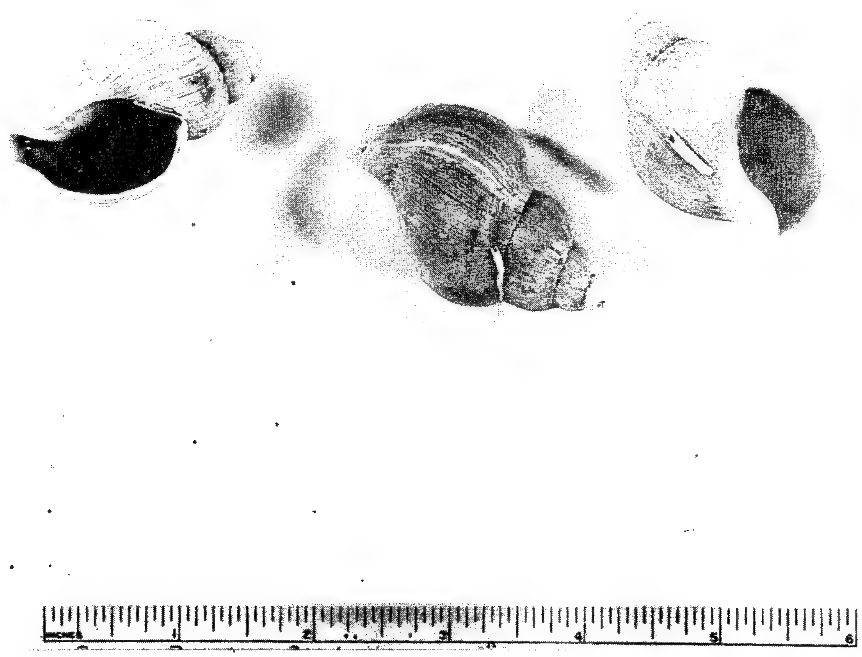


Figure 14. Deep sea gastropods (snails).

Figure 15. Deep ocean sea anemone.

Figure 16. Various types of wood panels (exterior).

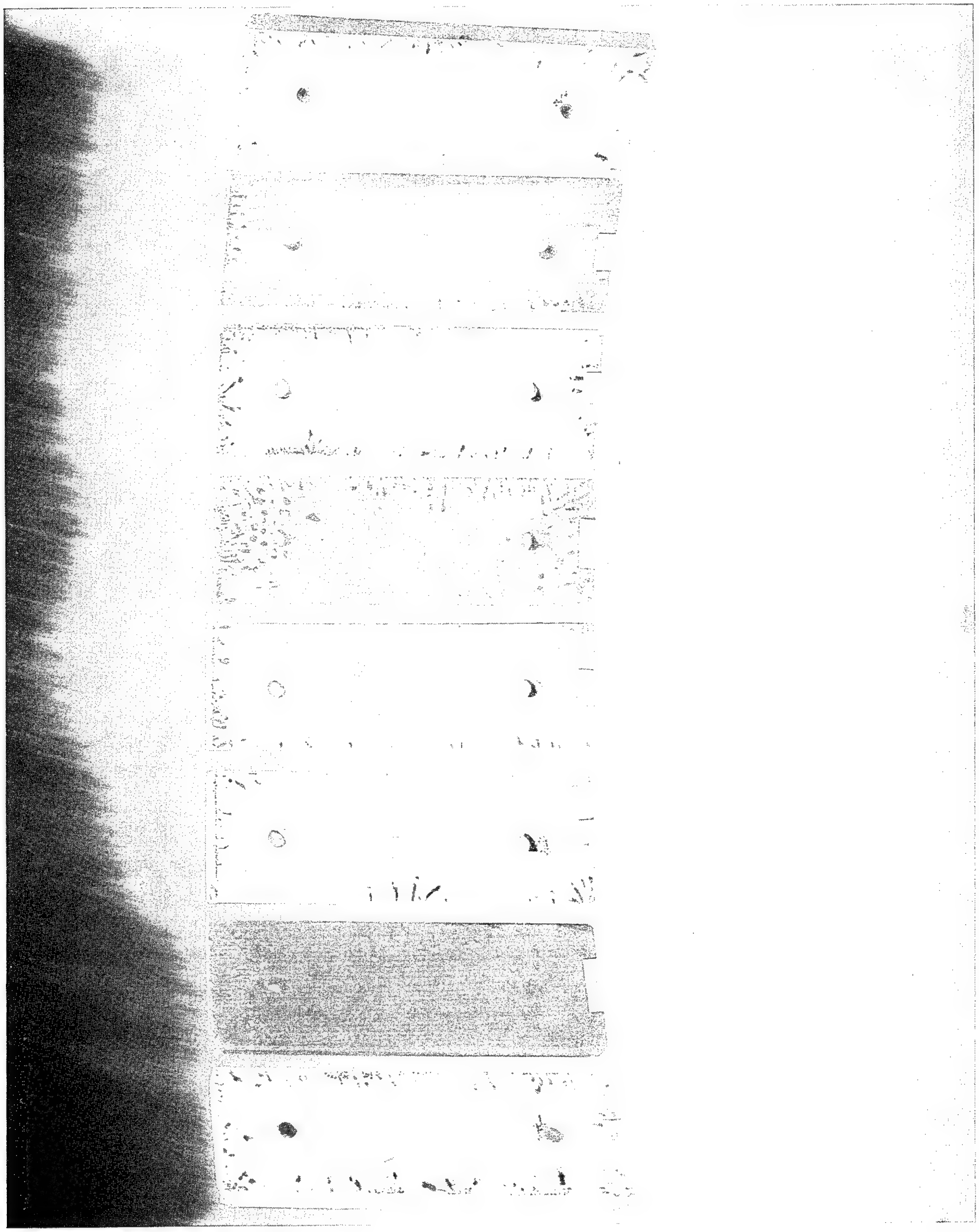


Figure 17. Same wood panels as shown in Figure 16 (interior).

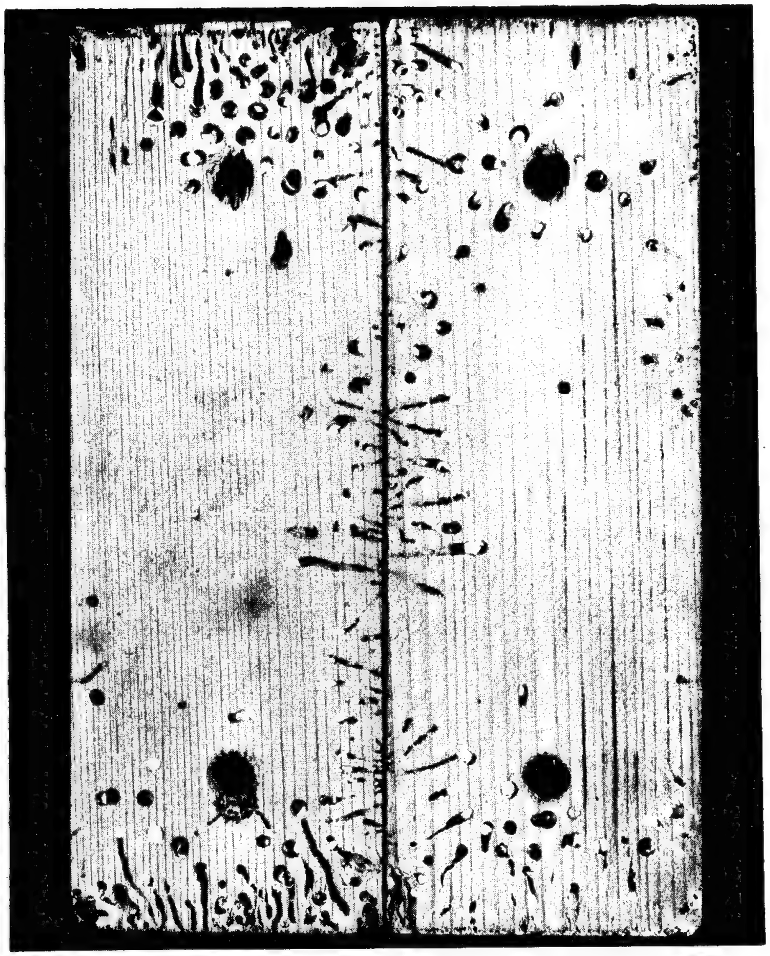


Figure 18. Closeup view of interior side of cedar (l.) and redwood panels.

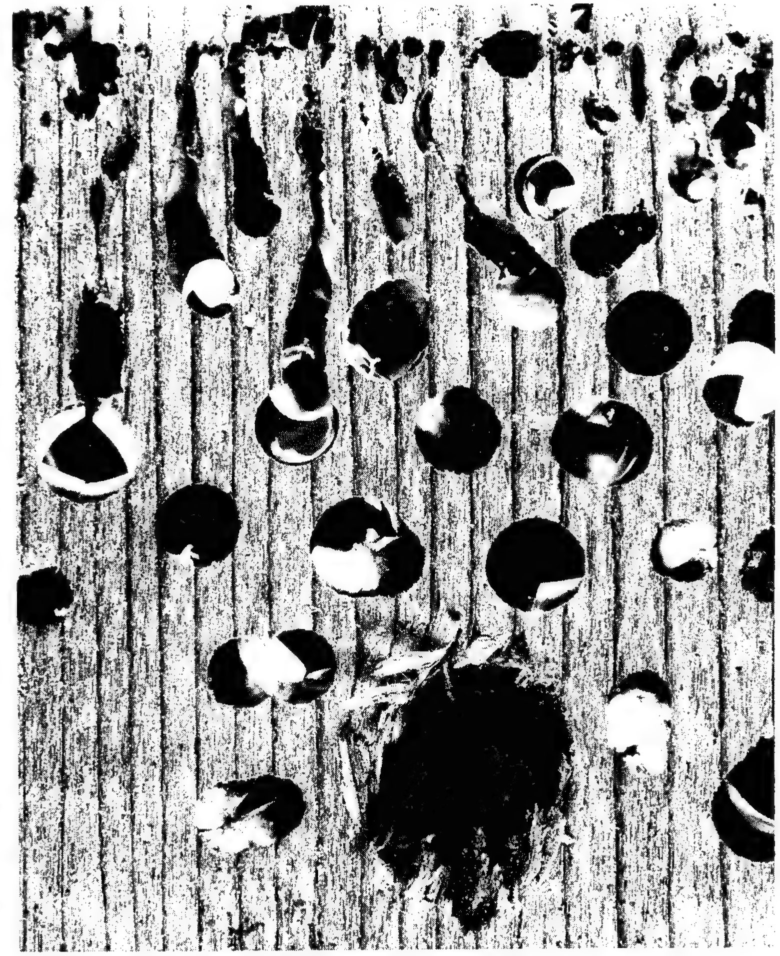


Figure 19. Closeup view of cedar panel showing 1/8-inch-diameter marine borers in holes.

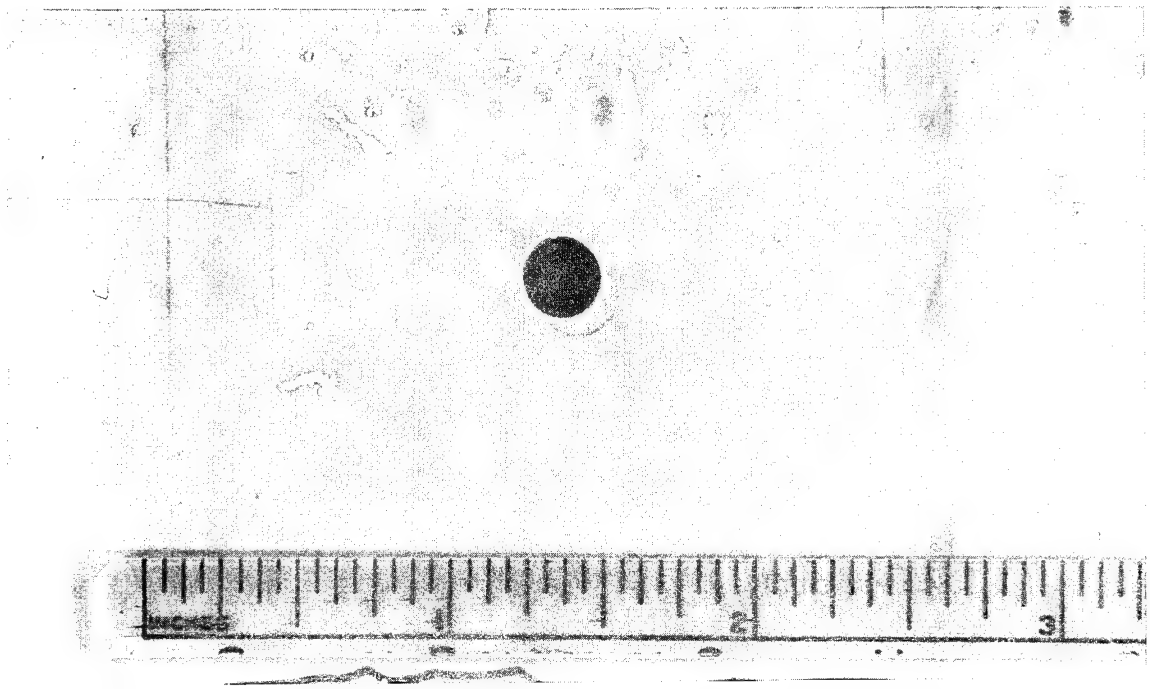


Figure 20. Phenolic laminated plastic sheet damaged by borers in an area which was in contact with wood. Compare size of damage to 1/4-inch-diameter bolt hole.

The surface of the phenolic laminated plastic sheet where the wood panels were attached was damaged by these borers (Figure 20). The borers had attacked the wood first and had then continued to bore into the plastic. Deep sea fungi were not found in any of the 1/2 x 2 x 6-inch panels which were exposed about 3 feet above the sediment layer. However, the surfaces of these wood panels were slightly deteriorated by bacterial action.

The 2 x 4 x 30-inch untreated fir bait pieces which were fitted over the plastic rods and tubes were deteriorated by borers. The heaviest damage was confined to the bottom side of a bait piece exposed right next to the sediment (Figures 21 & 22). Generally the large bait pieces were in fairly good condition, because the borers had not had time to penetrate deeply.

On the other hand, the 1/2 x 1 x 10-inch bait pieces which were fitted over the electrical cable insulations were heavily damaged. The interior of the wood was completely destroyed, leaving a thin outer shell. These wood bait pieces could easily be broken in two or crushed with one's fingers.

A 3/4 x 3 x 36-inch untreated plywood specimen was exposed between 5 and 8 feet above the mud line. As expected, the damage by the borers was very light compared to wood exposed near the mud line (Figure 23). At the lower end of the plywood board were attached clusters of egg sacks of some unknown marine animals (Figure 24).

Figure 21. Untreated fir bait piece damaged by borers.

Figure 22. Closeup view of Figure 21 showing borers and borer damage.

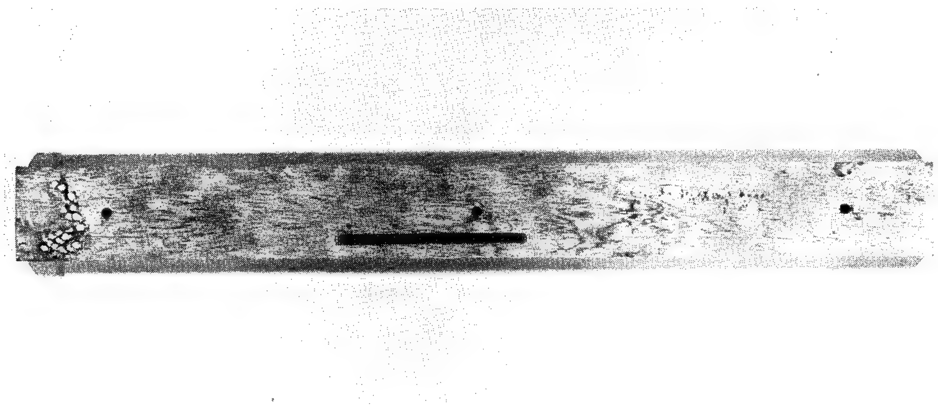


Figure 23. 3/4 x 3 x 36-inch plywood board.

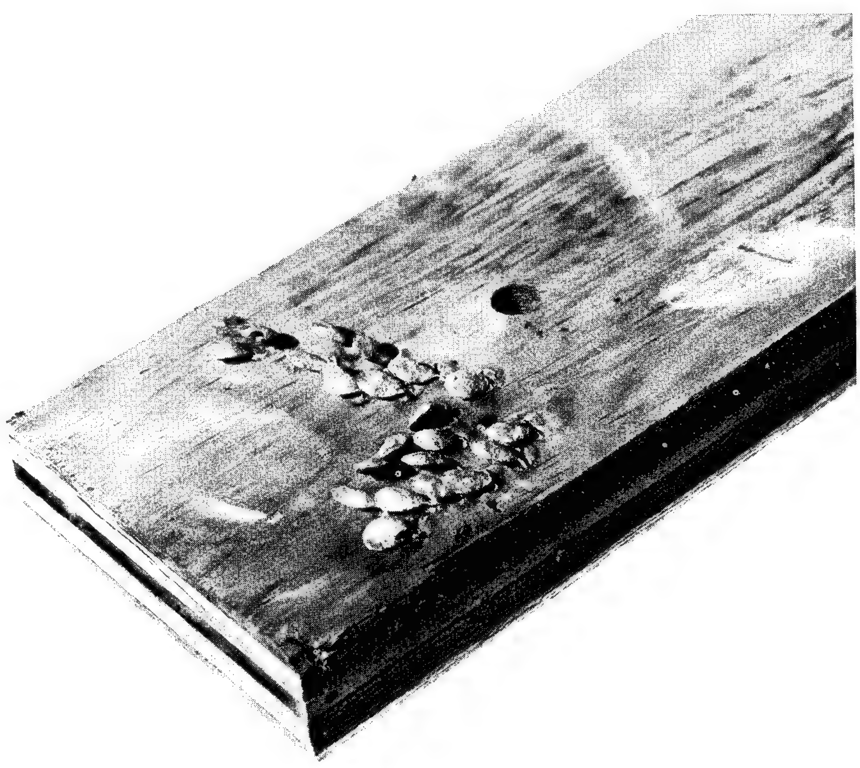


Figure 24. Cluster of egg cases of unknown animal attached to a plywood board.

If the wood panels were treated with preservatives which are effective against shallow water borers, it is possible that they would also resist deep water borers. However, wood panels treated with various kinds of preservatives should be exposed in the deep ocean to confirm this, because the borers found in the deep ocean are different from the ones found in shallow waters.

Tropical Wood Panels. Tropical wood specimens such as greenheart, *Afambeau*, and *Antidesma pulvinatum* were exposed to determine their resistance to marine borers. In northern Europe and in some tropical areas, the use of naturally resistant wood is more common than the use of creosote-treated timbers for pilings. One of the most widely used of the naturally resistant timbers is probably greenheart (*Octea rodiaei*). It is grown commercially in British Guiana and is often called Demerara greenheart. The high resistance of greenheart to marine borers has been attributed to the presence of toxic alkaloids. These alkaloids have been isolated and were found to be quite toxic to *Teredo*, a molluscan borer, but less toxic to *Limnoria*, a crustacean borer (Reference 8).

The three tropical wood specimens were attacked by borers (Figure 25). Of these, greenheart sustained the heaviest damage with 14 borers per square inch. The shells of some borers measured about 1/8 inch in diameter, and the borers had penetrated over 1/4 inch into the wood. *Afambeau* had 7 immature borers per square inch. The borers had penetrated about 1/32 to 1/16 inch. *Antidesma* was the most resistant of the three tropical wood specimens, with only 2 immature borers per square inch. These borers had penetrated about 1/32 to 1/16 inch. This information was obtained from an examination of a single panel of each of the tropical wood specimens which were exposed about 1 foot above the sediment layer.

Rope Specimens. A heavy slime growth was present over the surface of cotton and manila ropes, and a light slime growth was present over the surface of nylon and polypropylene ropes.

The fibers of cotton were decayed considerably by bacterial action and, as a result, were easily torn apart by one's fingers. The borers were not found on the surface of any of the cotton rope specimens. A test revealed that the cotton rope specimens had lost about 85% of their breaking strength. The 1/2-inch-diameter manila rope specimens were completely destroyed by both borers and microorganisms. Borers ranging in size from 1/32 to 1/8 inch in diameter had completely infested the entire length of the 5-foot-long rope specimens (Figure 26). The rope fibers were severed from deep penetration. The slime bacteria were also responsible for the decay and deterioration of the fiber materials.

Examination of the nylon and polypropylene ropes under stereoscopic microscope showed that the fibers of these ropes were not damaged by marine borers. On the contrary, they were in very good condition (Figure 27). Table 4 compares the breaking strength of these rope specimens before and after deep sea exposure.

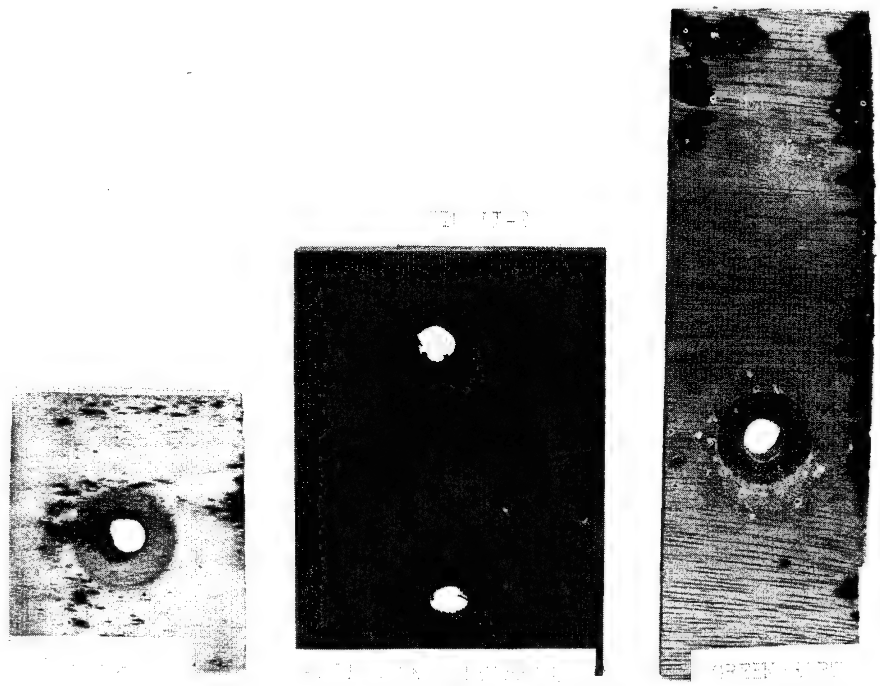


Figure 25. Tropical wood specimens (l. to r.) Afambeau, Antidesma pulvinatum, and greenheart.

Figure 26. Manila rope specimen completely destroyed by the combined action of borers and microorganisms.

Figure 27. Polypropylene, nylon, and cotton rope specimens.

Table 4. Breaking Strength of Rope Specimens Before and After Deep Sea Exposure (STU II-2)

Rope Material	Diam (in.)	Breaking Strength (lb)		
		Unexposed Specimens 1/	Exposed Specimens	
			On Bio-Racks 1/	Inside Plastic Tube 1/
Cotton	1/2	1,340	200	522
Manila	1/2	2,068	Completely deteriorated by marine organisms	1,805
Nylon	1/4	1,900	1,482	1,557
Polypropylene	5/16	1,810	1,570	1,687

1/ Average of 2 specimens

Plastic Specimens. The 3-foot-long plastic rods and vinyl tubes, recovered after 13.4 months on the sea floor in 2,370 feet of water, are shown in Figure 28. There were numerous borer holes, both deep and shallow, underneath the area where the wood bait pieces were fitted over the lower and upper sections of the plastics (Figure 29). Generally, the lower section, exposed about 0.5 to 1 foot above the sediment layer, had more borer holes than the upper sections which were exposed about 3 feet above the sediment. In other words, the borers were found to be more active near the sediment than 3 feet above the sediment layer.

The following plastic sheet, rods, and vinyl tubes were damaged by borers under the wood bait piece: delrin, nylon, phenolic laminates, polycarbonate, Teflon, cellulose acetate, extruded acrylic, polystyrene, and vinyl tubes (NCEL Nos. 424 and 425). Polyvinyl chloride pipe (unplasticized), polyethylene, cast acrylic, and a vinyl tube (NCEL No. 422) were not damaged by borer activity under the bait piece.

These borers were also able to bore into the surface of certain plastic materials directly from the seawater environment without the aid of any wood bait piece. On some plastics such as on polystyrene, the attack occurred along the edge of plastic-tape wrappings (Figure 30). On a vinyl tube (NCEL No. 425), there were as many as 300 shallow borer holes, and many of these holes contained immature borers (Figure 31). The deepest penetration into plastic by these borers occurred on a solid phenolic laminated plastic rod (NCEL No. 415). Several borers had penetrated over 1/16 inch into this plastic, and the shells of these borers were about 1/16 inch in diameter (Figure 32). The following plastics were also attacked by the borers directly from seawater: delrin, polycarbonate, cellulose acetate, polyethylene, cast acrylic and polystyrene rods; and vinyl tubes (NCEL Nos. 424, 425, and 426). These are shown in Figure 33. The number and size of the borer holes found on the surface of the plastic specimens are presented in the Appendix.

A vinyl tube (NCEL No. 412) intended for low-temperature use had a heavy bacterial slime growth over the entire tube and over the plastic, rubber, and burlap wrappings; the other three vinyl tubes intended for various other uses had a light slime growth over the entire surface. Perhaps the vinyl tube (NCEL No. 412) contains a plasticizer or some other chemical which serves as a source of food for the growth of microorganisms.

Moisture absorption and hardness tests were performed on the recovered plastic specimens which had been stored in plastic containers filled with fresh seawater aboard ship. These tests were conducted in a room which was kept at a constant temperature of 23°C and a relative humidity of 20%. The information about the amount of moisture absorbed and the hardness of these plastic materials is presented in Table 5.

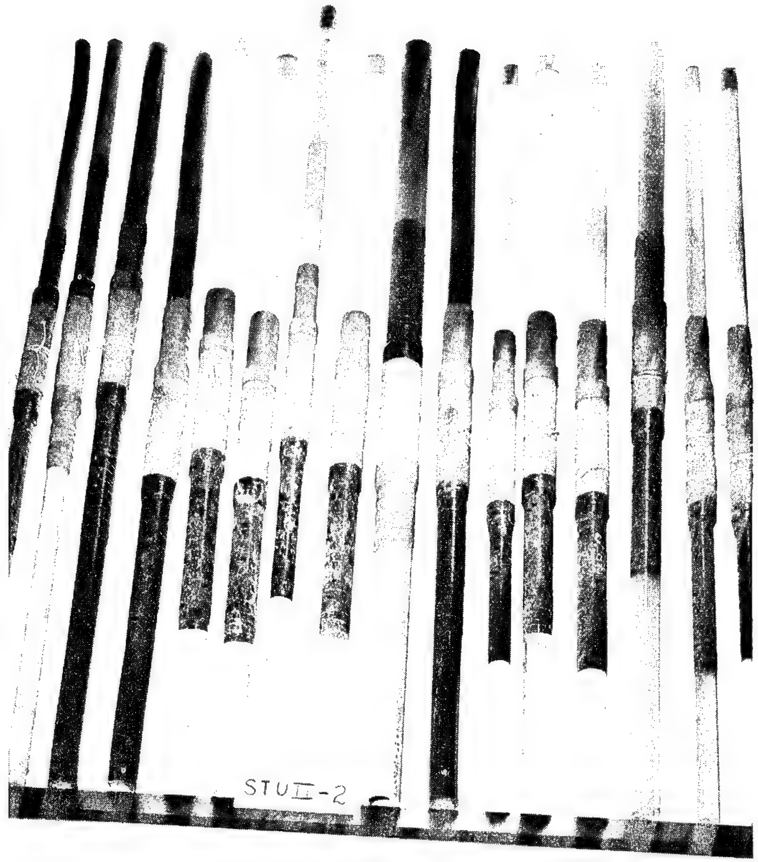


Figure 28. Various types of plastic rods, tubes, pipe, and a rubber vacuum hose with wrappings.

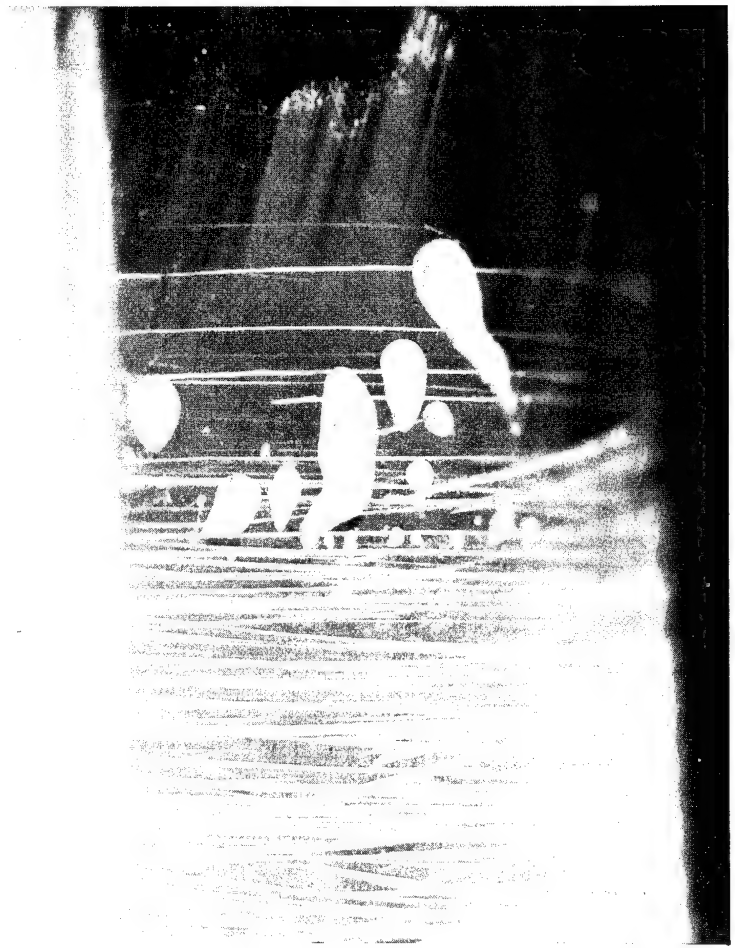


Figure 29. Borer damage on the surface of a cellulose acetate rod under area of wood bait piece.

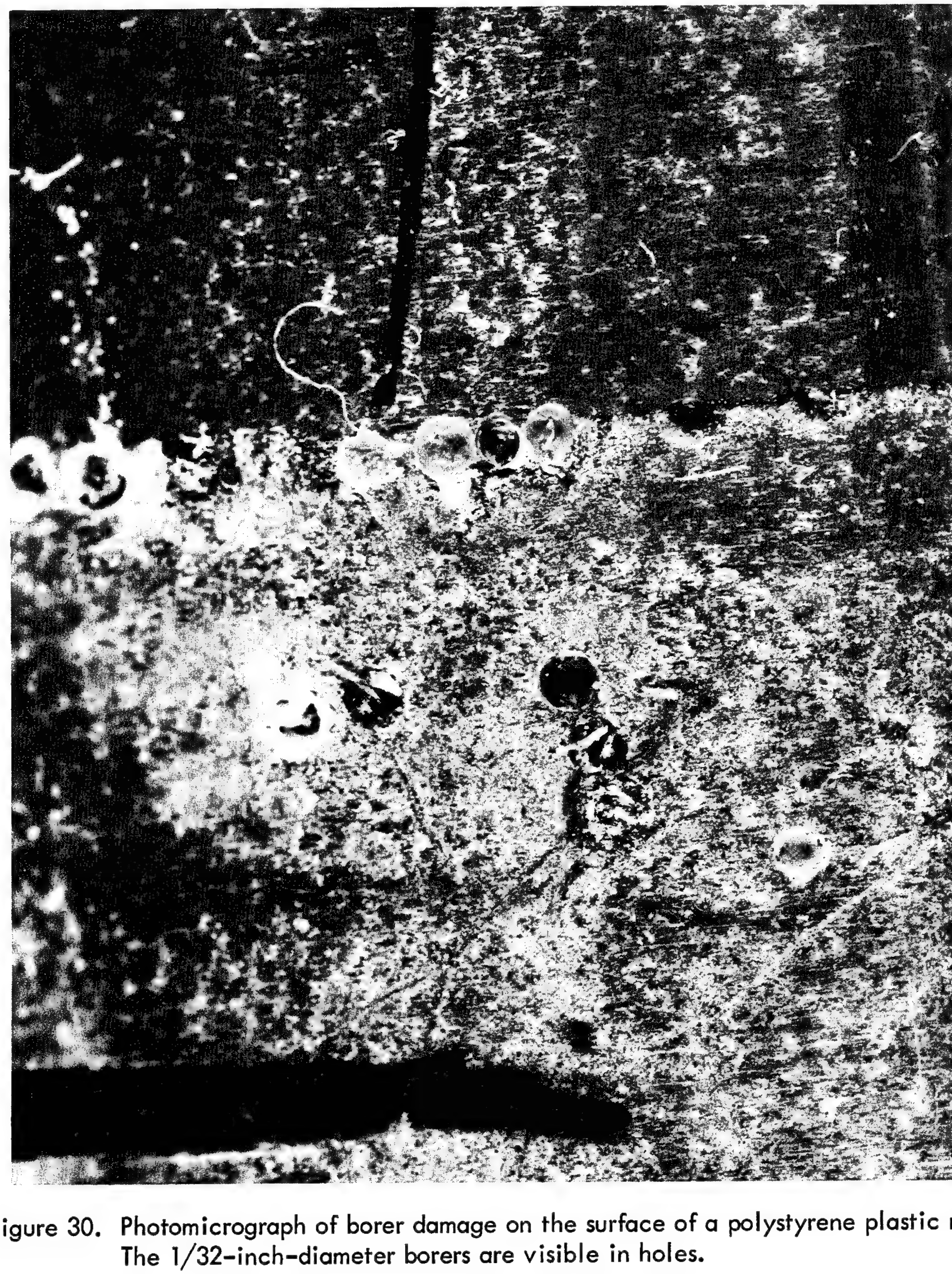


Figure 30. Photomicrograph of borer damage on the surface of a polystyrene plastic rod. The 1/32-inch-diameter borers are visible in holes.

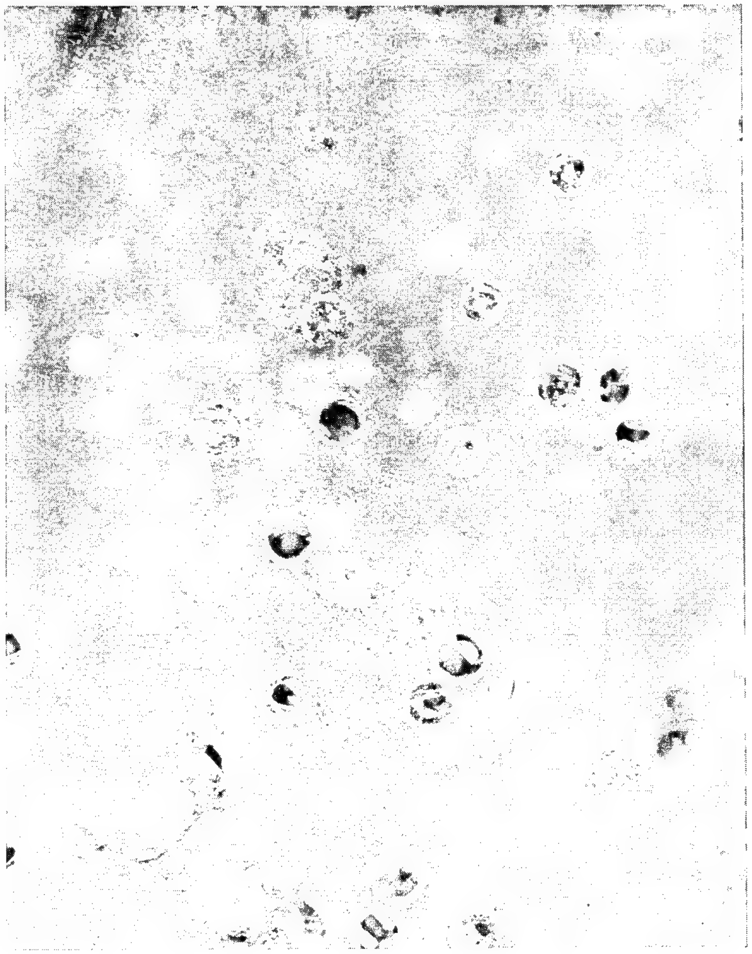


Figure 31. Photomicrograph of borer damage on the surface of a polystyrene plastic rod. The 1/32-inch-diameter borers are visible in holes.

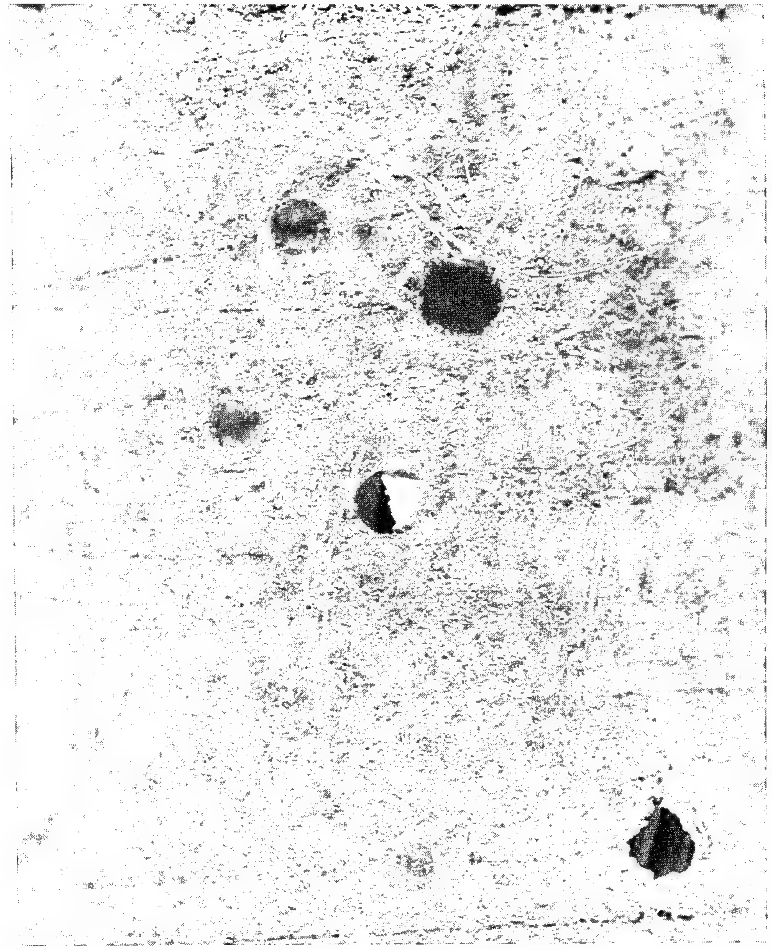


Figure 32. Photomicrograph of borer damage on the surface of a phenolic laminated plastic rod. A 1/16-inch-diameter borer is visible in a hole.

Table 5. Hardness and Moisture Absorption Tests on Plastics (STU II-2)

Plastic Materials	NCEL No.	Durometer Readings 1/ (Model "D")		Moisture Absorption (%) 1/
		Control (Dry)	Exposed (Wet)	
Rods				
Delrin	413	86	80	0.31
Nylon	414	80	65	1.48
Phenolic laminate	415	91	82	2.28
Polycarbonate	416	86	80	0.21
Teflon	417	62	57	0.001
Cellulose acetate	419	80	70	3.08
Polyethylene	420	52	50	0.004
Extruded acrylic	421	91	80	0.44
Polystyrene	422	88	83	0.05
Cast acrylic	423	93	85	0.46
Pipe				
Polyvinyl chloride	418	81	75	0.29
Tubes				
Vinyl	412	30	30	0.41
Vinyl	424	74 2/	73 2/	0.57
Vinyl	425	74 2/	74 2/	0.13
Vinyl	426	61	58	0.29
Laminates				
Phenolic	S-5	93	90	3.77
Phenolic	S-7	93	89	2.63
Phenolic	S-8	94	90	3.91
Phenolic	S-9	89	85	1.70
Melamine	S-10	98	95	0.46
Epoxy	S-11	95	92	0.19
Rubber				
Rubber vacuum tube	411	—	—	1.21

1/ Tested and dried for 2 months in 20% RH and 23°C temperature.
2/ Softer plastics tested with Model "A-2" durometer.

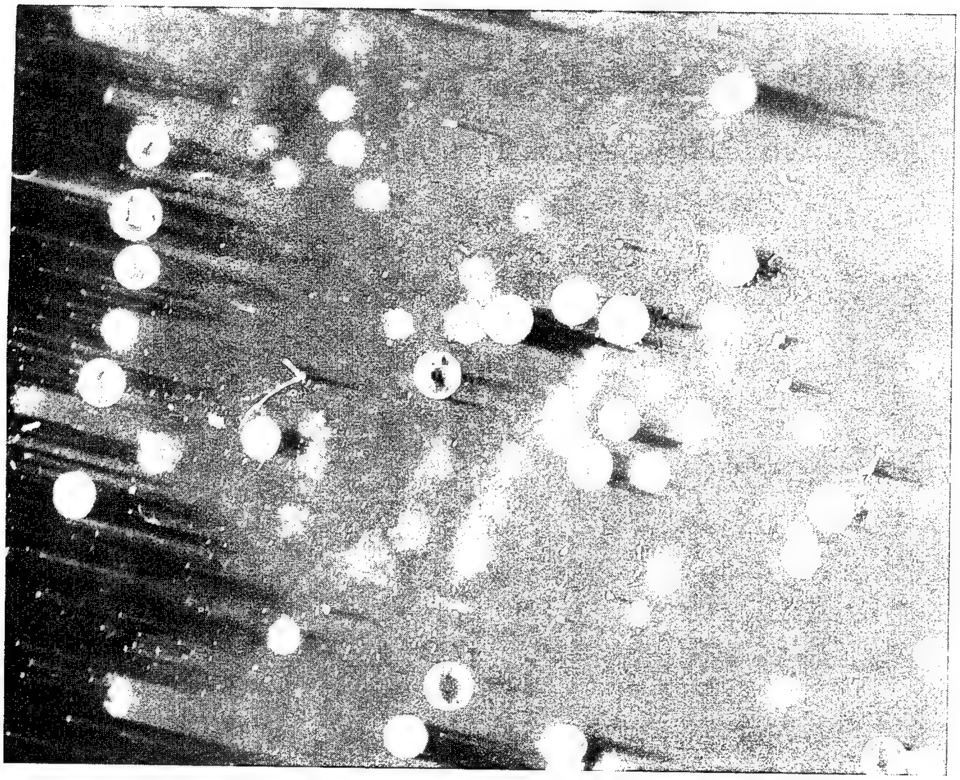


Figure 33. Photomicrograph of borer damage on surface of a vinyl tube. Some of the borer holes are about 1/32 inch in diameter and about 1/32 inch deep.

Wrappings Around Plastics. The burlap wrappings were moderately deteriorated by microbial activity, and the material could easily be torn apart by hand. The rubber electrical tape wrappings were not affected by marine organisms, although there was a light hydroid growth on the rubber material. Slight cracks were present in the rubber, and these were probably produced by the effects of the deep sea environment. The plastic tape wrappings were not affected by marine borers; however, there was some hydroid growth on them (Figure 34).

Electrical Insulation (0.015-Inch Thick) on No. 16 Wire. In the laboratory, the insulation of the 15-inch-long wire specimens was examined under a stereoscopic microscope for signs of deterioration. In addition, tests of insulation resistance (non-destructive) and voltage breakdown (destructive) were conducted on these specimens. The results of the electrical tests are presented in Table 6.

The entire surface of the silicone rubber insulation, exposed near the sediment, was roughened, and the thickness of the insulation was reduced considerably by the nibbling and chewing action of some unknown marine organisms. The surfaces of other insulations, such as polyvinyl chloride, polyethylene, government rubber styrene (GR-S), and neoprene were not affected. A silicone rubber cement which was used to seal the ends of the wire specimens was neither affected by marine organisms nor by the deep sea environment.

Table 6. Insulation Resistance and Voltage Breakdown Tests (STU II-2)

Insulation (15 mils thick)	Insulation Resistance (Megohms)		Voltage-Breakdown 5/
	Before Exposure 1/	After Exposure	
Exposed about 0.5 foot above the sediment 2/			
Straight wires			
Polyethylene	20,100,000	4,000,000	Did not fail
Polyvinyl chloride	4,400,000	600,000	Did not fail
Silicone rubber	6,200,000	292,000	Failed
GR-S (SBR) rubber	5,500,000	320,000	Did not fail
Neoprene	36,000	14,000	Did not fail
Exposed about 3 feet above the sediment 3/			
Straight wires			
Polyethylene	20,100,000	885,000	Did not fail
Polyvinyl chloride	4,400,000	240,000	Did not fail
Silicone rubber	6,200,000	208,000	Did not fail
GR-S (SBR) rubber	5,500,000	225,000	Did not fail
Neoprene	36,000	12,400	Did not fail
Placed in plastic tube about 4 feet above the sediment 4/			
Straight wires			
Polyethylene	20,100,000	480,000	Did not fail
Polyvinyl chloride	4,400,000	192,000	Did not fail
Silicone rubber	6,200,000	197,000	Did not fail
GR-S (SBR) rubber	5,500,000	158,000	Did not fail
Neoprene	36,000	8,700	Did not fail

1/ Average of 8 tests
2/ Average of 2 tests
3/ Average of 3 tests
4/ Average of 3 tests; end membrane filters ruptured, and specimens were covered with mud.
5/ Tested at 1,000 volts AC for 10 seconds.

Figure 34. Rubber tape, burlap (jute), and plastic tape wrappings over plastic rods and pipe.

Electrical Cable Insulation Over Single Conductors and Multiconductors. The insulation of the 10-inch-long electrical cable specimens was examined under a stereoscopic microscope for signs of any biodeterioration and for any physical effects of the deep ocean environment.

The wood bait pieces were riddled by the borers. However, only silicone rubber insulation and polyethylene insulation were damaged by borer activity under the bait piece exposed near the sediment, and that damage was slight. The other insulations, such as butyl rubber, neoprene rubber, natural rubber, polyvinyl chloride, nylon, fluorinated ethylene propylene (FEP) and Teflon were unaffected by animal activity or by the deep ocean environment (Figure 35).

The surfaces of silicone rubber specimens which were exposed about 1 foot and 3 feet above the sediment were damaged by the nibbling and biting action of some unknown marine organisms. As a result of this type of damage over the entire surface area (except underneath the area of cable clamps), the thickness of the insulation was reduced considerably. The silicone rubber cement which was used to seal the ends of some of the cables was not affected.

Laminated Plastics. The phenolic, epoxy, and melamine resin laminated plastic specimens were not damaged (Figure 36). The results of moisture absorption and hardness tests conducted on these materials are presented in Table 5.

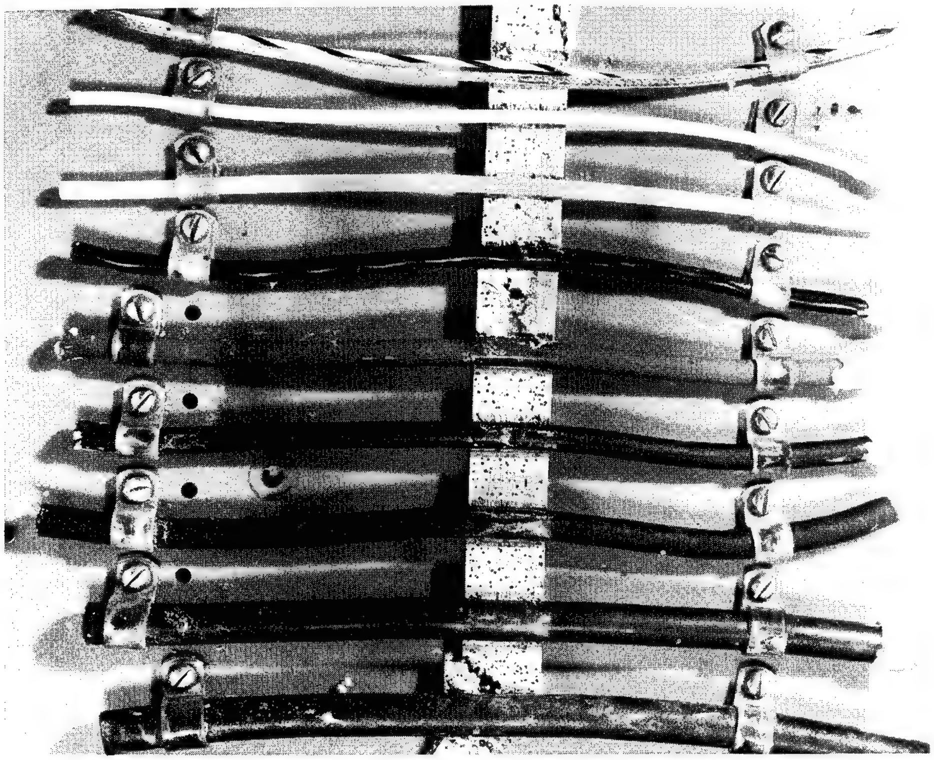


Figure 35. Single and multiconductor electrical cable insulations in contact with wood bait piece.

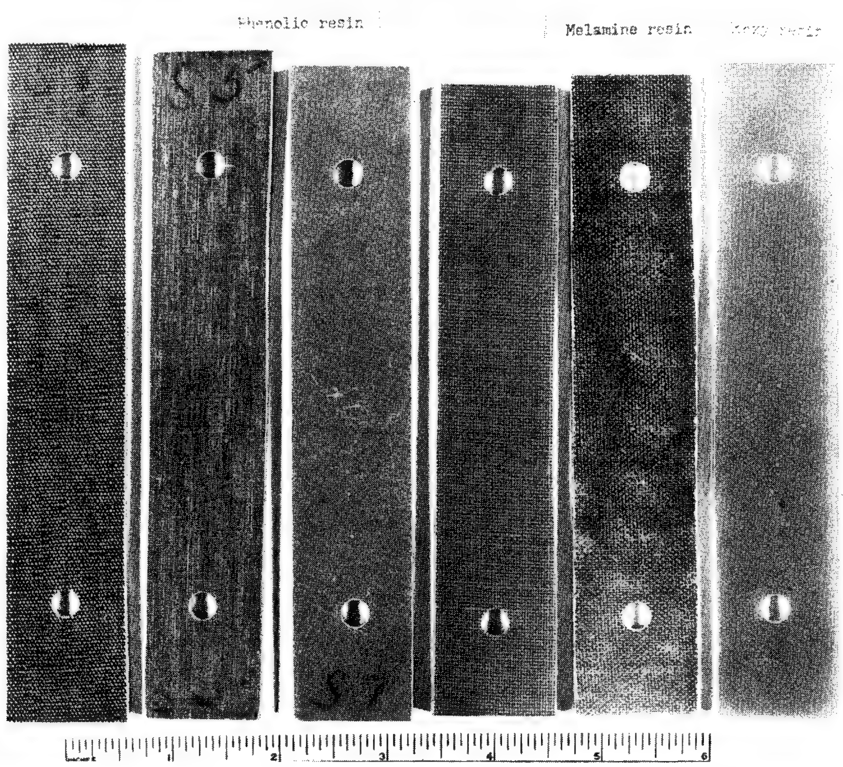


Figure 36. Phenolic, epoxy, and melamine resin-filled laminated plastics.

A phenolic resin plastic sheet (1/8 x 12 x 30 inches), onto which smaller test specimens were attached and then secured to the bio-racks, was damaged by borers. The damage was confined to the area where the wood panels were secured to the plastic sheet. The borers had attacked the wood first and had then continued to penetrate into the surface of the plastic sheet.

Plastic Sheet. A 0.020 x 4 x 4-inch white, high-impact styrene sheet which was used as a spacer between the large wood bait piece and the metal bio-rack was damaged by borers (Figure 37).

Glass Microscope Slides. Except for some microbial forms and hydroid growth over the surface of the glass, microscopic examination revealed no visible effects of etching or frosting by microorganisms (Figure 38). Photomicrographs of some of the deep sea microbial forms found on the glass are shown in Figures 39 and 40.

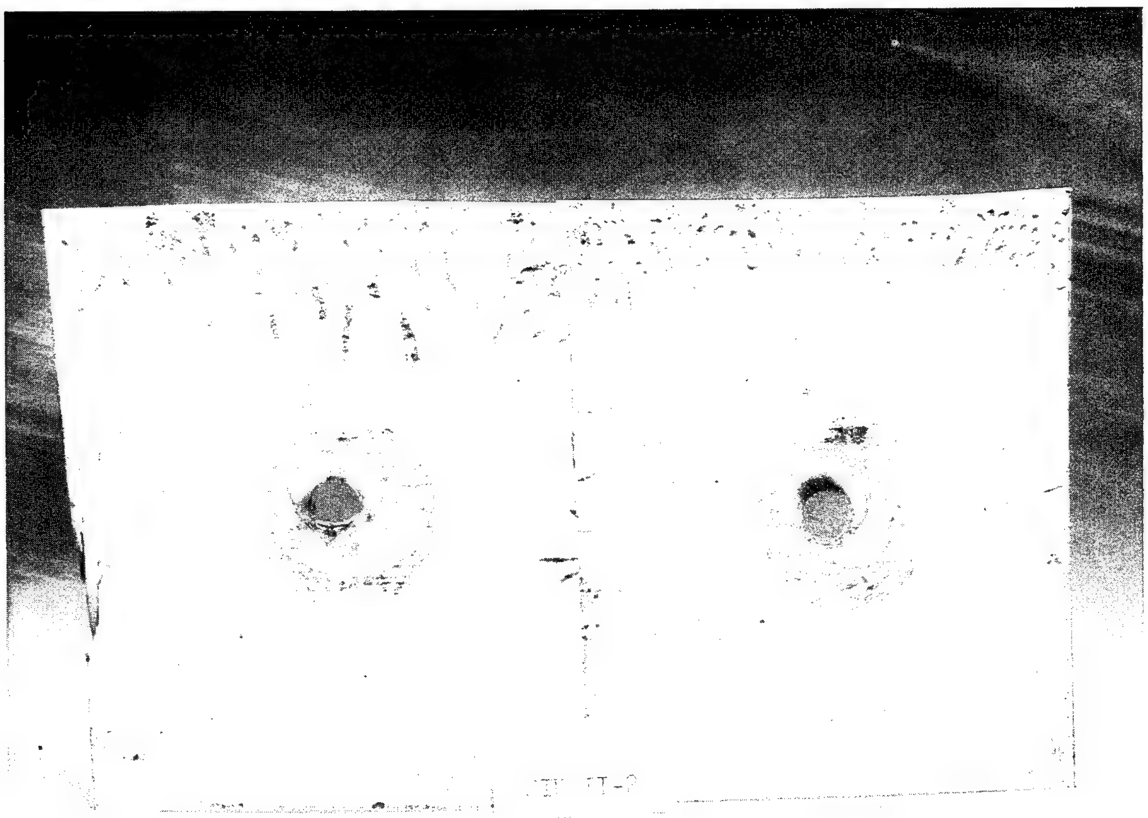


Figure 37. Borer damage to 20-mil-thick high-impact styrene sheets which were in contact with wood bait piece.

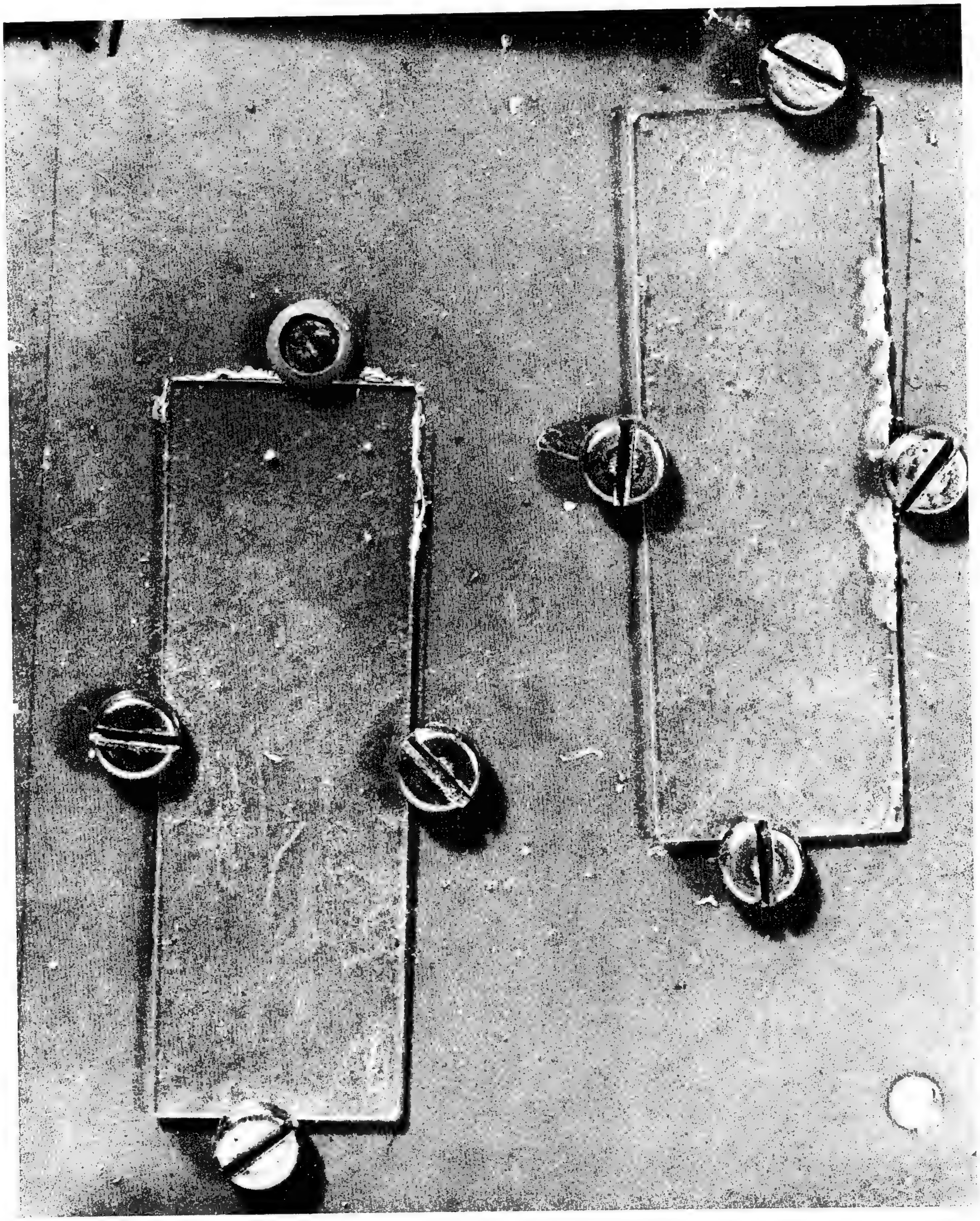


Figure 38. Microscope slides attached to a phenolic laminated sheet.

Figure 39. Deep sea microbial forms and bottom detritus on glass slide (1,000X).

Figure 40. Deep sea microbial forms and bottom detritus on glass slide (1,000X).

Polyurethane Foam. A specimen of soft and spongy polyurethane foam was recovered with no visible deterioration caused by marine organisms. It was also not affected in any way by the deep sea environment. Information on the manufacture and application of polyurethane foam is presented in Reference 9.

Polyethylene Foam. No visible deterioration caused by marine organisms could be detected on the recovered semirigid polyethylene foam. However, the specimen had decreased in dimension and had folded in two as a result of environmental effects (Figure 41). The foam material did not return to its original dimension and shape even after it had been dried. The reason for this could be that this foam material is composed of closed cells and that these cells had ruptured when the foam was lowered to the ocean floor, thereby permanently changing its shape.

It is possible that both of these plastic foam materials could be deteriorated by marine borers if the materials were placed directly against wood bait pieces.

Deep Ocean Borers

The species of borers found in wood and plastic specimens have been identified as *Xylophaga washingtona* Bartsch, a wood-boring Pholadidae. Other pholads related to *Xylophaga* are the rock-borers such as *Penitella*, *Zirfaea*, and *Barnea*, and a wood-borer, *Martesia*, which does considerable damage to waterfront structures. The average growth rate of *Xylophaga washingtona* in wood panels was as follows: At 4 months, 1/32 inch; at 6 months, 3/32 inch; at 13 months, 3/16 inch; at 24 months, 7/16 inch; and at 35 months, 11/16 inch. Species of *Xylophaga duplicata* Knudsen which were found together with *Xylophaga washingtona* in wood exposed at Test Site I were not found in wood exposed at Test Site II. New species of these deep sea borers were discovered in the wood panels and the description of these borers will be published in the near future.

The natural habitat, the life cycle of the adult borers, and the length of the free-swimming stages of the larval forms remain a mystery. There are also many other unanswered problems concerning the biology and distribution of this interesting and destructive group of borers. Additional information on *Xylophaga washingtona* and *Xylophaga duplicata* is found in References 10 and 11.

Materials in Plastic Test Chamber

The materials which were placed in the sterile plastic test chamber were covered with fine bottom sediment, because the membrane filters used to seal the ends of the tube had been ruptured either during descent or by marine animals at the bottom. Some of the materials at the bottom of the tube were buried in this fine sediment. Finding mud in the plastic tube was surprising, especially because the tube was exposed about 4 feet above the sediment layer. This indicates that the bottom waters, flowing at about 0.06 knot (data obtained with a current meter) at this particular test site, are rather turbid.

Figure 41. Polyurethane foam (l) and polyethylene foam (r).

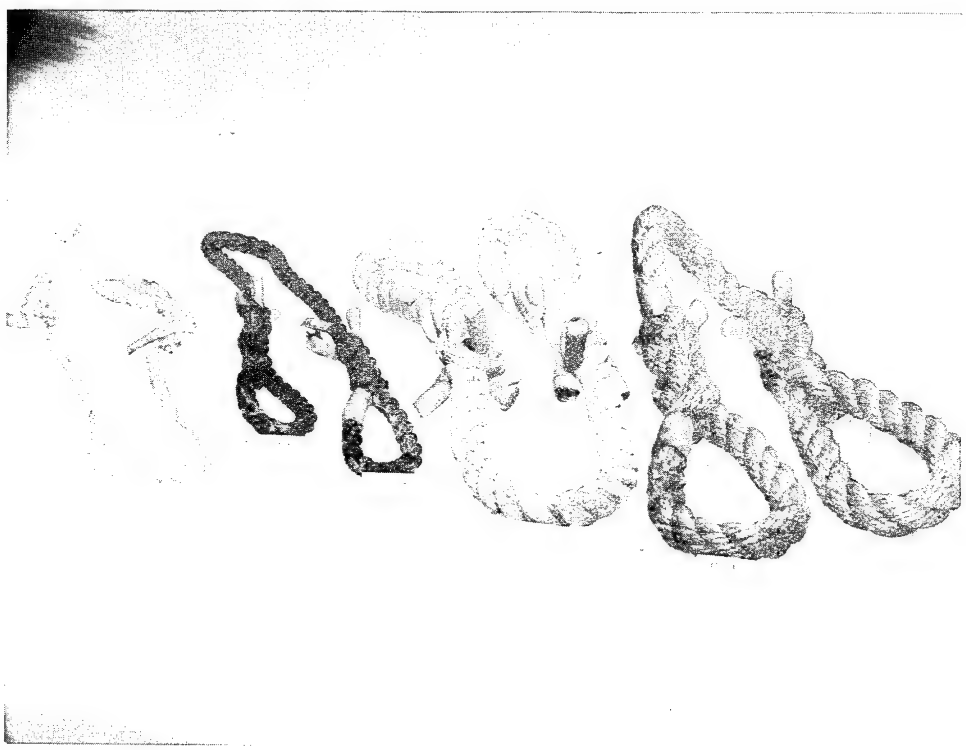


Figure 42. Rope specimens which were placed inside a plastic test chamber.

When the tube with the mud was examined the day following retrieval, a strong hydrogen sulfide odor was detected coming from the mud. This indicated that there were sulfate-reducing bacteria present which had produced hydrogen sulfide gas. One or more of the reasons why the metallic and nonmetallic test specimens were relatively free of various fouling organisms (although numerous deep sea animals such as snails, crabs, and marine borers were found on test panels) include the presence of turbid currents, low water temperature, hydrogen sulfide in the mud zone, and the small amount of dissolved oxygen (minimum oxygen zone) found at this test site.

Generally, the materials placed in the plastic tube were not deteriorated as severely as those materials exposed outside the tube (Figure 42). The fir panel was moderately attacked by borers, with some borers measuring about 1/4 inch in diameter. The fibers of cotton and manila rope specimens were slightly deteriorated by microorganisms. Borers were not found in manila rope specimens. The synthetic rope specimens were in excellent condition. The various electrical cable insulations (15 mils thick) on No. 16 wire were not affected. However, a large section of the white polyvinyl chloride insulation had turned black after being exposed to the hydrogen sulfide in the mud (Figure 43). This change occurred probably because there may have been small quantities of lead in the PVC insulation, and this lead had reacted with hydrogen sulfide to form lead sulfide, which is black. Small test strips of white polyvinyl chloride materials such as this could probably be used to detect the presence of hydrogen sulfide in an anaerobic environment, especially in areas where conventional testing devices cannot be placed or used for detecting hydrogen sulfide.

FINDINGS

1. There is considerable biological activity in the sediment at Test Site II (2,370 feet).

2. Sulfate-reducing bacteria which produce hydrogen sulfide seem to be present in large numbers in the sediment.

3. Light slime and hydroid growth, a large sea anemone, a few tubeworms, some large gastropods (snails), and crabs were found on the metal and nonmetallic specimens. Typical fouling organisms such as bryozoa, barnacles, and tunicates found on submerged panels in shallow water were not found on these panels.

4. Marine microorganisms were responsible for the deterioration of cotton and manila rope specimens, wood surfaces, and burlap (jute fibers).

5. Marine borers identified as *Xylophaga washingtona* Bartsch were responsible for the slight to heavy deterioration of the following materials: wood panels such as pine, cedar, fir, oak, maple, ash, redwood, plywood, greenheart, *Afambeau*, and

Antidesma; plastic rods such as delrin, nylon, phenolic laminate, polycarbonate, Teflon, cellulose acetate, polyethylene, extruded acrylic, cast acrylic, and polystyrene; vinyl tubes; manila ropes; phenolic laminated sheet; and high-impact styrene sheet.

6. Electrical cable insulation composed of silicone rubber was deteriorated by the nibbling and biting action of some marine animals. White polyvinyl chloride insulation changed to black when exposed to hydrogen sulfide produced by sulfate-reducing bacteria in the mud.

7. The following materials in various forms and for various uses were not affected by marine organisms: unplasticized polyvinyl chloride pipe; butyl rubber, neoprene, natural rubber, plasticized polyvinyl chloride, nylon, fluorinated ethylene propylene, GR-S rubber, and Teflon electrical cable insulation; various plastic laminated sheets; glass microscope slides; rubber vacuum tubing; nylon nuts and bolts; nylon and polypropylene ropes; ethyl cellulose cable clamps; and a plastic, pressure-sensitive electrical insulation tape.

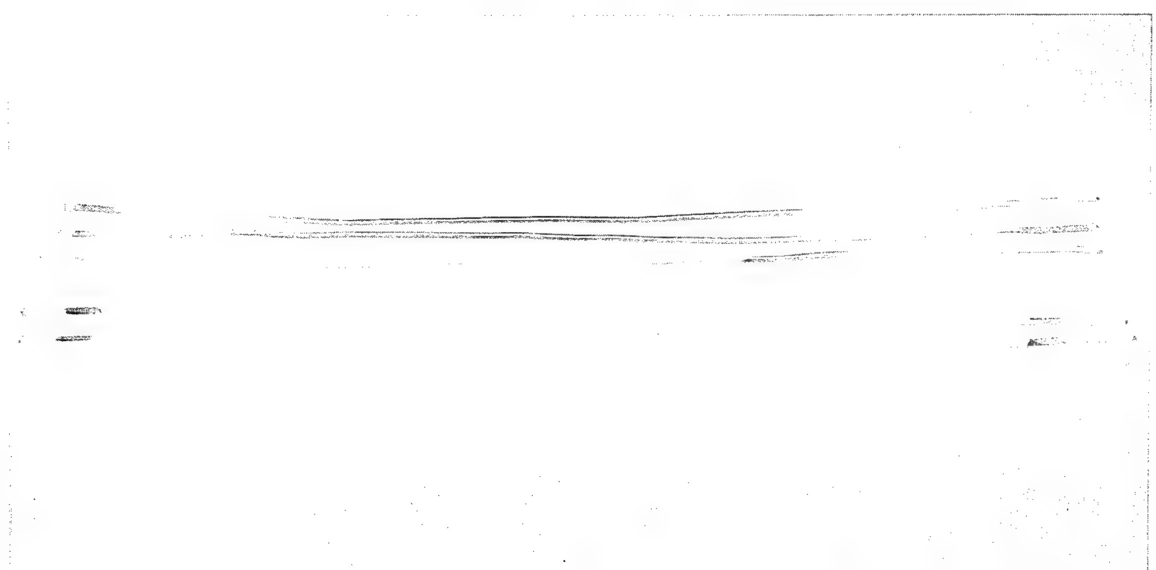


Figure 43. Sections of white polyvinyl chloride insulation exposed to bottom mud had changed to black.

CONCLUSIONS

1. The following materials are susceptible to total biological destruction within a relatively short time: untreated wood, including tropical wood; manila and cotton ropes; and burlap (jute fibers). It is assumed that wood panels treated with wood preservatives which are effective against borers in shallow waters may be equally protected against deep sea borers. However, exposure tests in the deep sea should be conducted to confirm this.

2. The following materials were not attacked and, therefore, are probably not susceptible to biological deterioration at this particular deep ocean site: PVC pipe; butyl rubber, neoprene rubber, natural rubber, PVC, nylon, FEP, GR-S rubber, and Teflon electrical cable insulations; various plastic laminated sheets; glass microscope slides; rubber vacuum tubing; nylon nuts and bolts; nylon and polypropylene ropes and ethyl cellulose cable clamps; and plastic electrical insulation tape.

3. Some of the 3-foot-long plastic rods and tubes which were damaged by borers in the area of the wood bait pieces can probably be used in the deep ocean if they are not placed in direct contact with wood. Other plastic rods and tubes which were susceptible to direct attack by borers from the seawater environment are not recommended for such use. Plastics for deep ocean use should be selected with caution, because some will absorb considerably more moisture than others and thereby change their physical characteristics. For example, Teflon and polyethylene rods absorbed the least amount of water, while cellulose acetate rods, phenolic laminates, and nylon rods absorbed considerable amounts of water by comparison. As a result, the hardness of some of the plastic materials had changed considerably.

COMPARISON OF TEST SITES I AND II

Since this is the last of a series of reports on biodeterioration of materials exposed to date at Test Sites I (6,000 feet nominal depth) and II (2,500 feet nominal depth), findings of significant differences at these two locations will be briefly discussed. In order to better compare the results on biodeterioration at the two locations, identical materials were placed on each of the six STUs. However, there were a few different items placed on each STU, depending upon the availability of the test materials at the time.

Factors Found Common at Both Locations

The following marine organisms were found at both STU sites: (1) slime bacteria, molluscan borers, hydroids, tubeworms, pectens, and sea anemones; (2) some unknown marine organisms which had deteriorated the surface of silicone rubber electrical

insulations; (3) marine borers, Xylophaga washingtona, had penetrated the surfaces of various plastic specimens in an area where the plastic was in contact with wood bait pieces; (4) marine organisms found in mud samples collected at both test sites were sulfate-reducing bacteria, aerobic and anaerobic bacteria, amphipods, annelid worms, cumacean, ophiuroids, bivalve molluscs, and Foraminifera tests. Similarity in effect on specimens was as follows: (1) the borers and microorganisms inflicted severe damage to manila rope specimens which were exposed on or right above the sediment layer; (2) identical rope specimens which were exposed 3 to 4 feet above the sediment layer were moderately damaged; (3) marine microorganisms were responsible for the deterioration of cotton rope and burlap specimens; and (4) marine bacteria had deteriorated the surfaces of the wood panels.

Factors Found Only at Test Site I

The following marine organisms were found only at Test Site I: (1) A white lobsterlike crustacean was found on a test panel; (2) marine borers, Xylophaga washingtona and Xylophaga duplicata, were found in wood panels (only species of Xylophaga duplicata were found in greenheart, a tropical wood noted for its resistance to marine borers); (3) numerous stalked organisms (hydroids), possibly a Tubularia specie, were found on metallic as well as nonmetallic test panels; (4) on numerous large and small rock specimens collected from the sea floor (largest, 500 pounds) were found species of bryozoa (erect and colonial forms), tubeworms, gorgonians, Foraminifera, solitary coral, chiton, brittle stars, glass sponges, and egg cases of unknown animals; (5) small white starfish, limpets and species of deep sea sponges were found on test materials; (6) a nemertean (round worm) and a holothurian (sea cucumber) were the other mud-dwelling animals found in sediment samples; and (7) marine fungi which were found on wood panels had deteriorated the surface of the wood.

Factors Found Only at Test Site II

The following marine organisms were found at Test Site II: (1) spider crabs and snails; (2) only Xylophaga washingtona were found in wood panels including tropical woods such as greenheart, Afambeau, and Antidesma (the activity of this specie seems much more pronounced than at deeper depths); and (3) the sediment at this site seems to contain more sulfate-reducing bacteria than in sediments found in the vicinity of Test Site I.

Since the sulfate-reducing bacteria are usually found in an anaerobic environment, the seawater at Test Site II could be expected to contain very little dissolved oxygen, and therefore, the seawater could be slightly stagnant in the mud zone or at the mud-seawater interface. It is anticipated that considerable detrimental effects will be experienced by certain types of metallic as well as nonmetallic materials exposed in such environments.

FUTURE PLANS

This series for placing STUs on the ocean floor to determine the effects of the deep ocean environment on materials has been completed. Future plans include the following:

1. The effects of fouling and boring animals on materials exposed at a depth of about 200 feet off the coast of Port Hueneme will be investigated. There is very little information available in the literature about fouling and biodeterioration of materials at this depth.

2. A laboratory and field study to determine the role of marine microorganisms in the corrosion of metals has been initiated.

3. Additional oceanographic cruises to the STU test sites to obtain additional information on bottom currents, temperatures, vertical distribution of marine bacteria (surface to bottom), deep ocean animals, etc., will be conducted.

4. Exposure of test panels treated with antifouling compounds and wood preservatives in the deep ocean may be conducted to determine their effectiveness against marine borers and fouling organisms.

ACKNOWLEDGMENTS

The author wishes to thank Dr. Ruth D. Turner, Museum of Comparative Zoology, Harvard University, for identifying the marine borers and Dr. Jan Kohlmeyer, Institute of Fisheries Research, University of North Carolina, for examining the wood panels for the presence of marine fungi.

APPENDIX—Biological Effects on Materials Assembled on Bio-Racks of STU II-2

Materials	NCEL No.	Size and Description	Summary of Results	Remarks
Plastic rods		3-ft-long specimens commercially available through catalogs.		Slime and hydroid growth were present on all the materials. See result of water absorption and hardness test presented in Table 5.
Delrin	413	3/4 in. diam, yellow.	4 borer holes; the largest measured about 5/32 in. wide by 1/32 in. deep.	The borer holes were made in the area of a wood bait piece which was exposed about 0.5 ft above the sediment layer.
			20 additional small borer holes along the edge of the plastic tape.	The borers had attacked the plastic directly from seawater environment about 1 ft above the sediment.
			6 borer holes under wooden bait piece.	Exposed about 3 ft above the sediment.
			Over 15 borer holes directly into plastic without the aid of wood. The majority of the holes measured about 1/32 in. wide by 1/32 in. deep.	Exposed about 3 ft above the sediment.
Nylon	414	3/4 in. diam, type I.	5 borer holes under wood bait piece; 1/8 in. wide by 1/64 in. deep.	Exposed about 0.5 ft above the sediment.
			15 borer holes under wood bait piece; 1/8 in. wide by 1/64 in. deep.	Exposed about 3 ft above the sediment.
Phenolic laminate	415	3/4 in. diam, no. 911.	5 borer holes under wood bait piece.	Exposed about 0.5 ft above the sediment.
			30 borers had started to penetrate directly into the plastic without the aid of wood. Of these, 6 borers were found deep inside the plastic. The holes measured about 1/16 in. wide by 1/16 in. deep. The borers were fully developed.	This is the deepest the borer had ever penetrated into plastic directly from seawater.

APPENDIX—Continued

Materials	NCEL No.	Size and Description	Summary of Results	Remarks
Polycarbonate	416	3/4 in. diam	Single borer hole at the edge of the plastic tape; 1/32 in. wide by 1/64 in. deep.	Exposed about 1 ft above the sediment.
			2 borer holes under bait piece; 1/8 in. wide by 1/16 in. deep.	Exposed about 3 ft above the sediment.
Teflon	417	3/4 in. diam	3 borer holes under wood bait piece; 1/16 in. wide by 1/32 in. deep.	Exposed about 0.5 ft above the sediment.
Cellulose acetate	419	1 in. diam	12 borer holes under wood bait piece. Some holes were about 3/32 in. wide by 1/32 in. deep.	Exposed about 0.5 ft above the sediment.
			About 6 borer holes along the edge of plastic tape.	Exposed about 1 ft above the sediment.
			17 borer holes under wood bait piece. Some holes were about 3/32 in. wide by 1/32 in. deep.	Exposed about 3 ft above the sediment.
Polyethylene	420	1 in. diam	Numerous very shallow borer holes and etch marks over the surface of the plastic where the borers had attempted to penetrate it without the aid of wood pieces.	
			Numerous shallow borer holes along the edge of the plastic tape.	Majority of the borers had started to bore into the plastic.
Extruded acrylic	421	1 in. diam	Six shallow borer holes under wood bait piece.	Exposed about 0.5 ft above sediment.
Polystyrene	422	1 in. diam	150 borer holes. A few borers had penetrated about 1/16 in. deep. The borers were buried inside the plastic.	Plastic was attacked directly from seawater environment.
			About 150 borer holes along the edge of the plastic tape. The immature borers were partially buried in the plastic.	Exposed about 1 ft above the sediment. The area underneath the wood bait piece was not damaged by borer activity.

APPENDIX—Continued

Materials	NCEL No.	Size and Description	Summary of Results	Remarks
Cast acrylic	423	1 in. diam	One small borer hole over roughened area of the plastic.	Not affected by borers under wood bait piece.
Plastic pipe				
Polyvinyl chloride (PVC)		3 ft long, 1-5/16 in. OD.; gray, unplasticized.	Not affected by borers.	Small amount of hydroid growth.
Plastic tubes		3 ft long, 1 in. OD., 1/8 in. wall thickness; commercially available.		See result of water absorption and hardness tests presented in Table 5.
Vinyl	412	Flexible, low-temperature tube, black.	Not affected by borers. The entire tube was covered with heavy slime growth.	
Vinyl	424	Flexible, fuel and lubricating tube, yellow.	30 borer holes under wood bait piece. Some holes were 5/32 in. wide by 1/32 in. deep.	Exposed about 0.5 ft above the sediment.
			Numerous small borer holes on the surface of plastic.	Surface of plastic attacked directly from seawater environment.
Vinyl	425	Flexible, general utility chemical hose, black.	3 borer holes under wood bait piece. One measured 1/8 in. wide by 1/64 in. deep.	Exposed about 3 ft above the sediment.
			10 borer holes on the surface of plastic. Plastic attacked directly from seawater.	Area exposed 3 ft above the sediment.
			6 borer holes under wood bait piece.	Exposed about 0.5 ft above the sediment.
			Over 300 tiny borer holes along the edge of plastic tape. Majority of the holes measured about 1/32 in. wide.	Area exposed about 1 ft above the sediment.
Vinyl	426	Semirigid, general utility chemical hose, black.	Over 100 small borer holes on the surface of the plastic. Majority of the holes measured about 1/32 in. wide.	Attacked directly from seawater environment in an area exposed about 0.5 ft above the sediment.

APPENDIX—Continued

Materials	NCEL No.	Size and Description	Summary of Results	Remarks
Electrical cable (Insulation)		10 in. long; single conductor and multiconductor cables		A wood bait piece was in contact with each test material.
Butyl rubber jacket	427	0.508 in. OD., black.	Not affected.	In excellent condition.
	428	0.508 in. OD., black.	Not affected.	In excellent condition.
Neoprene rubber	429	0.491 in. OD., black.	Not affected.	In excellent condition.
	430	0.491 in. OD., black.	Not affected.	In excellent condition.
Natural rubber	431	0.356 in. OD., black.	Not affected.	In excellent condition.
	432	0.356 in. OD., black.	Not affected.	In excellent condition.
Geon, PVC	433	0.323 in. OD., black.	Not affected.	In excellent condition.
	434	0.323 in. OD., black.	Not affected.	In excellent condition.
Silicone rubber	435	0.325 in. OD., blue.	Surface deteriorated by nibbling and biting action of some unknown marine animals.	Exposed about 3 ft above sediment.
	436	0.325 in. OD., blue.	Same as #435. Also ten small borer holes under wood bait piece.	
Bakelite, PVC	437	0.243 in. OD., black.	Not affected.	In excellent condition.
	438	0.243 in. OD., black.	Not affected.	In excellent condition.
Polyethylene	439	0.199 in. OD., low density, translucent.	Not affected.	In excellent condition.
	440	0.199 in. OD., low density, translucent.	2 shallow grooves under wood bait piece.	Exposed about 1 ft above sediment.
Nylon	441	0.155 in. OD., white, opaque.	Not affected.	In excellent condition.
	442	0.155 in. OD., white, opaque.	Not affected.	In excellent condition.
Fluorinated ethylene propylene (FEP)	443	0.120 in. OD., clear.	Not affected.	In excellent condition.

APPENDIX—Continued

Materials	NCEL No.	Size and Description	Summary of Results	Remarks
Fluorinated ethylene propylene (FEP)	444	0.120 in. OD., clear.	Not affected.	In excellent condition.
Teflon	445	0.080 in. OD., white with black stripes.	Not affected.	In excellent condition.
	446	0.080 in. OD., white with black stripes.	Not affected.	In excellent condition.
Laminated Plastic Sheet		1/8 x 1 x 6-inch specimens.		See Table 5 for moisture absorption and hardness tests. Exposed about 2 feet above the sediment. Slight amount of hydroid growth on all.
Laminate	S-5	Phenolic resin, fine weave, cotton fabric base, MIL-P-15035B, type FBG.	Not affected.	In excellent condition.
Laminate	S-7	Phenolic resin, fine weave, paper base, MIL-P-3115B, type PBE.	Not affected.	In excellent condition.
Laminate	S-8	Phenolic resin, cotton base fabric, MIL-P-15035B, type FBG.	Not affected.	In excellent condition.
Laminate	S-9	Phenolic resin, nylon fabric base, MIL-P-15047B, type NBG.	Not affected.	In excellent condition.
Laminate	S-10	Melamine resin, glass fabric base, MIL-P-15037B, type GMG.	Not affected.	In excellent condition.
Laminate	S-11	Epoxy resin, glass fabric base, MIL-P-18177, type GEE.	Not affected.	In excellent condition.
Laminated Plastic Sheet		1/8 x 12 x 30-inch phenolic resin.	Marine borers made numerous holes in an area where wood was in contact with the plastic.	The borers had attacked the wood first and then continued into the plastic.
Ropes				Splices for thimbles were placed at each end of the rope specimens before exposure in the sea. See result of breaking strength tests in Table 4.
Cotton		1/2 in. diam, 4 ft long, 2 specimens.	Fibers deteriorated by marine microorganisms.	The entire rope was covered with slime growth.

APPENDIX—Continued

Materials	NCEL No.	Size and Description	Summary of Results	Remarks
Manila		1/2 in. diam, 4 ft long, 2 specimens.	Completely destroyed by borers and marine microorganisms.	Rope was covered with slime growth.
Nylon		1/4 in. diam, 4 ft long, 2 specimens.	Not affected.	Rope was covered with light slime growth. Fibers seemed to be in excellent condition.
Polypropylene		5/16 in. diam, 4 ft long, 2 specimens.	Not affected.	Rope was covered with light slime growth. Fibers seemed to be in excellent condition.
Wood		1/2 x 2 x 6-inch panels.	Loss in weight of wood due to borer damage.	Control and test panels were dried at 95°C for 3 hours before conducting weight-loss test. Redwood, cedar, and pine heavily damaged; maple, ash, and oak were moderately damaged; fir was lightly damaged by borers. Fungi were not found on the surface of the panels. There was some surface damage due to bacterial activity.
Pine			20.5% loss in weight.	
Pine			29.0% loss in weight.	
Fir			3.1% loss in weight.	
Maple			15.5% loss in weight.	
Ash			12.4% loss in weight.	
Oak			17.4% loss in weight.	
Redwood			31.0% loss in weight.	
Cedar			34.6% loss in weight.	
Wood bait piece				
Douglas fir		Two 2 x 4 x 30-inch pieces bolted together over plastic rods and tubes.	The wood bait pieces were riddled by borers. The shells of majority of the borers in the wood measured about 1/8 in. diam. However, there were some as large as 1/4 in. diam.	The plastic rods and tubes were fitted inside these wood pieces so that a 4 in. area of the plastic materials was in contact with wood. These wood bait pieces were fitted over the lower and upper sections of the plastic rods and tubes.
Pine		Two 1/4 x 1 x 12-inch pieces bolted together over single conductor and multiconductor electrical cables.	The wooden bait pieces were riddled by borers.	Could easily be crushed with one's fingers.

APPENDIX—Continued

Materials	NCEL No.	Size and Description	Summary of Results	Remarks
Plywood				
Laminated wood		3/4 x 3 x 4-inch. Used as support blocks.	Riddled by borers.	Exposed about 0.5 ft above the sediment.
Laminated wood		3/4 x 3 x 36-inch.	Lightly attacked by borers.	Exposed about 5 ft above the sediment. There was a cluster of egg sacs attached to wood.
Tropical woods				
Greenheart		1/4 x 1-1/4 x 4-inch.	Moderately attacked by borers.	14 borers per square in. or a total of 200 borers per panel. The shell measured about 1/8 in. diam, and the borers had bored about 1/4-in. into the wood.
Afambeau		1/4 x 1-1/2 x 1-3/4-inch.	Lighrly attacked by borers.	7 immature borers per square in. or a total of 45 borers per panel. These had penetrated about 1/32 to 1/16 in. into the wood.
Antidesma		1/4 x 2 x 2-3/4-inch.	Lightly attacked by borers.	2 immature borers per square in. or a total of 25 borers per panel.
Electrical insulation		0.015-in.-thick insulation on no. 16 tin-coated wire., 15 in. long.		See results of insulation and voltage breakdown tests in Table 6.
Straight specimens		3 of each specimen.		Exposed about 0.5 and 3 feet above sediment.
Polyethylene			Not affected.	No visible deterioration.
Polyvinyl chloride (PVC)			Not affected.	No visible deterioration.
Silicone rubber			Surface damage due to biting and nibbling of some unknown marine organisms.	
Government rubber styrene (GR-S)		Styrene butadiene rubber (SBR).	Not affected.	No visible deterioration.

APPENDIX—Continued

Materials	NCEL No.	Size and Description	Summary of Results	Remarks
Neoprene rubber			Not affected.	No visible deterioration.
Wrappings around plastic rods and tubes				
Burlap (jute fiber)			Moderately deteriorated.	Fibers decayed by microorganisms.
Plastic insulation		Pressure-sensitive adhesive 0.010 in. thick, 3/4 in. wide, black.	Not affected by borers.	Moderate amount of hydroid growth. In good condition when recovered.
Rubber insulation		3/4 in. wide, 0.027 in. thick, gray, spec. HH-T-111C.	Slight amount of surface cracking from deep sea exposure.	Light amount of hydroid growth.
Others				
Glass microscope slides			Not affected.	No visible etching or frosting on the surface of glass.
Plastic cable clamps		1/16 x 3/8-inch clamps of various sizes, ethyl cellulose, yellow.	Not affected.	No visible deterioration. Probably could be reused.
Nylon nuts and bolts		1/4 x 1-inch, black.	Not affected.	No visible deterioration. Material was soft when wet, but hardened when dry.
Polyurethane foam		1 x 4 x 9-inch, yellow, soft and spongy.	No visible deterioration by marine organisms.	Not affected by deep sea environment.
Polyethylene foam		1 x 7 x 8-inch, white, semirigid.	No visible deterioration by marine organisms.	Decreased in dimension and had folded in two. Did not return to its original form and shape when dried.
Sterile test chamber		5 in. OD x 1/4-inch-thick wall x 2-ft-long acrylic tube.		The 0.45-micron membrane filters were ruptured. The test chamber with the materials was partially filled with fine sediment. A strong hydrogen sulfide odor was detected coming from the mud the following day.
Ropes				
Cotton		1/2 in. diam, 2 specimens.	Fibers slightly deteriorated by microorganisms.	See result of breaking-strength test in Table 4.

APPENDIX—Continued

Materials	NCEL No.	Size and Description	Summary of Results	Remarks
Manila		1/2 in. diam, 2 specimens.	Fibers slightly deteriorated by microorganisms.	Rope specimens were free of borer attack.
Nylon		1/4 in. diam, 2 specimens.	Not affected.	Fibers in good condition.
Polypropylene		5/16 in. diam, 2 specimens.	Not affected.	No visible sign of deterioration. Fibers in good condition.
Wood				
Fir panel		2 x 6 x 1/4 inch.	Moderately attacked by borers. The shells of some of the borers measured about 1/4 in. diam.	Covered with a film of mud.
Electrical insulation		0.015-in.-thick insulation, 15 in. long.	All the wires were covered with mud.	See result of insulation resistance and voltage breakdown test in Table 6.
PVC		White	The white insulation had turned black after exposure to hydrogen sulfide in the mud.	No visible deterioration other than change in color.
Polyethylene			Not affected.	No visible deterioration.
Silicone rubber			Not affected.	No visible deterioration.
Neoprene rubber			Not affected.	No visible deterioration.
GR-S (SBR) rubber			Not affected.	No visible deterioration.

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U. S. Naval Civil Engineering Laboratory
DEEP-OCEAN BIODETERIORATION OF MATERIALS — PART VI. ONE YEAR AT 2,370 FEET, by James S. Muraoka
TR-525 57 p. illus May 1967 Unclassified

1. Marine organism attack 2. Wood, metal, plastic, fibers I. Z-F015-01-99-006

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